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Identification of RFID Indoor System and Influence of the Propagation Parameters on the Localization Accuracy

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

Ahmed N. Rashid

Επιβλέπων Καθηγητής: Αβαριτσιωτης Ιωαννης

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ΜΙΛΤΙΑΔΗΣ Ε. ΑΝΑΓΝΩΣΤΟΥ
ΕΥΣΤΑΘΙΟΣ Δ. ΣΥΚΑΣ

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Ι. ΑΒΑΡΙΤΣΙΩΤΗΣ Μ. ΑΝΑΓΝΩΣΤΟΥ Ε. ΣΥΚΑΣ

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Κ. ΠΑΠΑΟΔΥΣΣΕΥΣ Γ. ΚΟΛΕΤΣΟΣ Ε. ΚΟΚΟΥΤΣΗΣ

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Γ. ΣΤΑΜΟΥΛΗΣ

Αθήνα, Ιούνιος 2014

Διδακτορική Διατριβή

....

Ahmed N. Rashid

Διδάκτωρ Ηλεκτρολόγος Μηχανικός και Μηχανικός Υπολογιστών Ε.Μ.Π.

ABSTRACT

While in the near future everything will be tagged with Radio Frequency Identification (RFID) tags, localization of these tags in their environment is becoming an important feature for many RFID-based ubiquitous computing applications. RFID is designed, by definition, to provide wireless object identification. It is developing fast and has become the industry standard for logistic and passport identification. RFID tags are usually very small, especially passive ones. The reading distance is enough for indoor use and RFID tags are very cheap. The issue being tackled here relates to the problem of object location in wireless sensor networks, a specific problem in localization. Localization primarily refers to the detection coordinates of a node or an object. RFID is one of the most promising technologies for indoor location awareness applications. This work constitutes of two sections:

1) It presents the Identification of Employees in National Technical University in Athens (IE-NTUA), when the employees access to a certain area of the building (enter and leave to/from the college). Radio Frequency Identification (RFID) is applied for identification by offering special badges containing RFID-tags, in order to reduce administration time and more importantly to keep status by storing a full academic record.

2) It introduces an approach named Multidimensional Scaling (MDS) for estimating the location of unknown RFID tags within the area to facilitate locating all tags in a RFID network and to reduce localization cost and environment complexity. It measures the distances between the reader and tags using the log normal distance path loss propagation model for indoor environment based on RSS measurement. The main advantage of this technique is the reduction in number of expensive RFID readers and moreover it can better tolerate noises. However, signals in indoor environments are generally harshly impaired because of multipath propagation and the variable factors in the surrounding environment, resulting in tags with very limited capabilities which pose many challenges for positioning them.

Multipath interference is avoided by selecting the strongest/maximum received signal for detection on RFID tags, which may have been dropped almost the RF-interference, because RSS has an inverse proportional relationship with a distance from receiving station (i.e., it has a short path between the transmitter and receiver), that will be leaded to decrease a measurement error of location estimation.

According to this condition, we present the effect of propagation parameters on localization accuracy by varying these parameters to observe probability distribution of estimated distance, where the propagation parameters in indoor environments make working with signal strength measurements challenging. Then we model the ratio of the effect path loss on the received signal strength for each RFID tag in the detection area which is determined by the reader. To alleviate measurement error on the location estimation, the proposed model is based on knowing the effect of path loss on the received strength for each RFID tag in the coverage area to measure the received signal, which has Maximum RSS relative to Minimum PL (*Max RSSPL*). The goal is to reduce distance between the estimated and the actual RFID tags position, which leads to reduce localization error and increase localization accuracy of our technique to get accurately the location of object tags.

Keywords: Radio Frequency Identification; Received Signal Strength; Multidimensional Scaling; Wireless Sensor Networks; Non-Line-of Sight; Radio Frequency.

Ταυτοποίηση RFID Συστήματος Εσωτερικού Χώρου και Επιρροή των Παραμέτρων Διάδοσης στην Ακρίβεια Εντοπισμού

ΠΕΡΙΛΗΨΗ

Καθώς στο εγγύς μέλλον τα πάντα θα σημαίνονται με ετικέτες ταυτοποίησης μέσω ραδιοσυχνοτήτων (RFID), ο εντοπισμός αυτών των ετικετών στο περιβάλλον τους αρχίζει να αποτελεί ένα σημαντικό χαρακτηριστικό για πολλές RFID-based πανταχού παρούσες υπολογιστικές εφαρμογές. Η τεχνική RFID έχει σχεδιαστεί εξ ορισμού, για να παρέχει ασύρματη ταυτοποίηση στοιχείων. Αναπτύσσεται γρήγορα και έχει γίνει το βιομηχανικό πρότυπο στην αναγνώριση και ταυτοποίηση προϊόντων. Οι ετικέτες RFID είναι συνήθως πολύ μικρές, ειδικά οι παθητικές. Η απόσταση ανάγνωσης είναι επαρκής για χρήση σε εσωτερικούς χώρους και οι ετικέτες RFID είναι πολύ οικονομικές.

Το ζήτημα που αναλύεται εδώ σχετίζεται με το πρόβλημα της θέσης αντικειμένου σε ασύρματα δίκτυα αισθητήρων, ένα συγκεκριμένο πρόβλημα στη διαδικασία εντοπισμού. Ο εντοπισμός (localization) αναφέρεται κυρίως στις συντεταγμένες εντοπισμού ενός κόμβου ή ενός αντικειμένου. Η μέθοδος RFID είναι μία από τις πλέον υποσχόμενες τεχνολογίες για εφαρμογές εσωτερικού χώρου που αφορούν την ταυτοποίηση θέσης. Αυτή η μελέτη αποτελείται από δύο μέρη:

1) Παρουσιάζει την Ταυτοποίηση των Εργαζομένων του Εθνικού Μετσόβιου Πολυτεχνείου (ΕΜΠ-ΙΕ), όταν οι εργαζόμενοι έχουν πρόσβαση σε μια συγκεκριμένη περιοχή του κτιρίου (είσοδο και έξοδο προς / από το πανεπιστήμιο). Η μέθοδος ταυτοποίησης μέσω ραδιοσυχνοτήτων (RFID) εφαρμόζεται για την ταυτοποίηση, παρέχοντας ειδικά αναγνωριστικά που περιέχουν ετικέτες RFID, προκειμένου να μειωθεί ο χρόνος διαχείρισης και το πιο σημαντικό για να διατηρηθεί το status αποθηκεύοντας μια πλήρη ακαδημαϊκή καταγραφή.

2) Εισάγει μια προσέγγιση που ονομάζεται Πολυδιάστατη Κλιμάκωση (MDS) για την εκτίμηση της θέσης άγνωστων ετικετών RFID μέσα στην περιοχή, ώστε να διευκολύνει τον εντοπισμό όλων των ετικετών σε ένα δίκτυο RFID και να μειώσει το κόστος εντοπισμού και την πολυπλοκότητα του περιβάλλοντος. Μετρά τις αποστάσεις μεταξύ αναγνώστη και ετικετών με τη χρήση του μοντέλου απώλειας διαδρομής, που συσχετίζει τις απώλειες με το λογάριθμο της απόστασης για το εσωτερικό περιβάλλον και το οποίο βασίζεται στη μέτρηση RSS. Το κύριο πλεονέκτημα αυτής της τεχνικής είναι η μείωση του αριθμού των ακριβών αναγνωστών RFID και η καλύτερη ανοχή θορύβου. Ωστόσο, τα σήματα σε εσωτερικούς χώρους είναι γενικά σημαντικά μειωμένα λόγω της διάδοσης πολλαπλών διαδρομών και των μεταβλητών παραγόντων στον περιβάλλοντα χώρο, με αποτέλεσμα ετικέτες με πολύ περιορισμένες δυνατότητες που θέτουν πολλές προκλήσεις για την τοποθέτησή τους.

Η παρεμβολή πολλαπλής διαδρομής αποφεύγεται επιλέγοντας το ισχυρότερο / μέγιστο λαμβανόμενο σήμα για ανίχνευση στις ετικέτες RFID, οι οποίες μπορεί να έχουν πέσει σχεδόν στις RF-παρεμβολές, επειδή το RSS έχει μια αντιστρόφως ανάλογη σχέση με την απόσταση από το σταθμό λήψης (δηλαδή, έχει ένα σύντομο μονοπάτι μεταξύ του πομπού και του δέκτη), το οποίο θα οδηγηθεί για μείωση του σφάλματος μέτρησης στην εκτίμηση της τοποθεσίας.

Σύμφωνα με αυτή την κατάσταση, παρουσιάζουμε την επίδραση των παραμέτρων διάδοσης στην ακρίβεια εντοπισμού, μέσω της μεταβολής αυτών των παραμέτρων για παρατήρηση της κατανομής πιθανοτήτων μιας υπολογισμένης απόστασης, όπου οι παράμετροι διάδοσης σε εσωτερικούς χώρους κάνουν την εργασία με μετρήσεις ενίσχυσης του σήματος να αποτελεί πρόκληση.

Έπειτα μοντελοποιούμε την αναλογία επίδρασης της απώλειας διαδρομής στο λαμβανόμενο σήμα για κάθε ετικέτα αναφοράς στην περιοχή ανίχνευσης η οποία καθορίζεται από τον αναγνώστη. Για τον περιορισμό του σφάλματος μέτρησης στην εκτίμηση της θέσης, το προτεινόμενο μοντέλο βασίζεται στη γνώση της επίδρασης της απώλειας διαδρομής στη λαμβανόμενη ισχύ για κάθε ετικέτα αναφοράς στην περιοχή κάλυψης, για τη μέτρηση του λαμβανόμενου σήματος, το οποίο έχει μέγιστο RSS ανάλογο του ελάχιστου PL (Max RSSPL). Ο στόχος είναι να μειωθεί η απόσταση μεταξύ της εκτιμώμενης και της πραγματικής θέσης των ετικετών RFID, κάτι που οδηγεί σε μείωση του σφάλματος εντοπισμού και σε αύξηση της ακρίβειας εντοπισμού της τεχνικής μας, ώστε να λάβετε ετικέτες ακριβούς τοποθεσίας ενός αντικειμένου.

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LIST OF ACRONYMS

RFID	Radio Frequency Identification
MDS	Multidimensional Scaling
RSS	Received Signal Strength
RF	Radio Frequency
LoS	Line-of Sight
NLoS	Non-Line of Sight
DLoS	Direct Line-of Sight
WSNs	Wireless Sensor Networks
SN	Sensor Nodes
GPS	Global Positioning System
GSM	Global System of Mobile
CDMA	Code Division Multiple Access Mobile Cellular Network
UWB	Ultra-Wide Band
TOA	Time of Arrival
TOF	Time of Flight
WLAN	Wireless Local Area Network
TDOA	Time Difference of Arrival
RSP	Received Signal Phase
AOA	Angle of Arrival
EPC	Electronic Product Code

LF	Low Frequency
HF	High Frequency
UHF	Ultra High Frequency
ISM	Industrial, Scientific, and Medical
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
FDMA	Frequency Division Multiple Access
PA	Procrustes Analysis
RTLS	Real-time Locating Systems
EVD	Eigenvalue Decomposition
ID	Identity Cards
LE	Localization Error
CDF	Cumulative Distribution Function
IEEE	Institute of Electrical and Electronics Engineers
Max RSSPL	Maximum Received Signal Strength relative to Pathloss

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I dedicate my work to my son Elias, as minimum remuneration for the period lacked my attention during authoring.

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1o ΚΕΦΑΛΑΙΟ

CHAPTER ONE

I

INTRODUCTION

1.1. Wireless Sensor Networking

A Wireless Sensor Networks (WSNs) is a network of small sensor nodes (SN) communicating among themselves using wireless communication, to sense the physical world. It combines distributed sensing, computation and wireless communication technologies. Distributed sensor networks have been discussed for more than 30 years, but the vision of WSNs has been brought into reality only by the recent advances in wireless communications and electronics, which have enabled the development of low-cost, low-power and multi-functional. Sensors that are small in size and communicate over short distances. Today, cheap, smart sensors, networked through wireless links and deployed in large numbers, provide unprecedented opportunities for monitoring and controlling homes, cities, and the environment. In addition, networked sensors have a broad spectrum of applications in the defence area, generating new capabilities for reconnaissance and surveillance as well as other tactical applications [1].

WSNs consist of a possibly large number of wireless devices able to take environmental measurements. Conditions such as temperature, sound, vibration, pressure, motion or pollutants could be monitored on a large scale using spatially distributed WSNs (from tens to thousands of nodes). Because of its variety in function and flexibility in deployment, numerous potential applications could be developed using WSNs. These sensor readings are transmitted over a wireless channel to a running application that makes decisions based on these sensor readings. Recently, there has been a great impetus to make these devices wireless, exploiting the advantages of wireless networks. First, wireless sensor networks do not need wiring. Installing wires for wired sensor networks in an existing building often are prohibitively expensive. Second, wireless sensor networks can be deployed in dangerous areas such as battle grounds and radioactively contaminated sites. Sensors can be dropped from an airplane or shot as projectiles. Third, wireless sensors can be deployed in places where electrical power is not readily available. Overall, wireless sensor networks can be used in a wider range of applications [2].

A wireless ad hoc network is a decentralized type of wireless network. The network is ad hoc because it does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity. In addition to the classic routing, ad hoc networks can use flooding for forwarding data. An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network device in link range. Ad hoc network often refers to a mode of operation of IEEE 802.11 wireless networks [3].

Wireless ad-hoc sensor network has recently attracted much interest in the wireless research community as a fundamentally new tool for a wide range of monitoring and data-gathering applications. Many applications with sensor networks are proposed, such as habitat monitoring, health caring, battle-field surveillance and enemy tracking, and environment observation and forecasting. It’s applied in some situations where most existing sensor positioning methods tend to fail to perform well, an example being when the topology of a sensor network is anisotropic [4].

1.2. Overview of Wireless Localization Techniques

In this chapter, we provide an overview of various aspects of WSNs systems with a focus on the applications covered in the chapter as well. A variety of methods have been developed for the purpose of object localization. Having identified the common measuring principles, the positioning algorithms and the important performance metrics of location positioning systems, we are able to discuss specific systems. There are two basic approaches to designing a wireless geolocation system. The first approach is to develop a signaling system and a network infrastructure of location measuring units focused primarily on wireless location application. The second approach is to use an existing wireless network infrastructure to locate a target. The advantage of the first approach is that the designers are able to control physical specification and, consequently, the quality of the location sensing results.

The tag with the target can be designed as a very small wearable tag or sticker, and the density of the sensor can be adjusted to the required positioning accuracy. The advantage of the second approach is that it avoids expensive and time-consuming deployment of infrastructure. These systems, however, may need to use more intelligent algorithms to compensate for the low accuracy of the measured metrics. Several types of wireless technologies are used for indoor location. ***Fig.1,*** depicts a rough outline of the current wireless-based positioning systems. We focus on the wireless positioning systems primarily for indoor situations. There are some classification approaches to surveying the indoor positioning system, such as application environments (such as 2-D/3-D positioning in office, warehouse, etc.), positioning algorithms, and wireless technologies [5].

1.2.1. GPS-Based

Global Positioning System (GPS), or its differential complement DGPS [6], is one of the most successful positioning systems in outdoor environments. It developed by the United States, is a localization technology based on a constellation of about 24 satellites orbiting the earth at altitudes of approximately 11,000 miles. Similar systems are being developed by other countries. As the most widely used localization system, GPS employs time-of-arrival of RF signals for localization. It measures the time delay between transmission and reception of each GPS radio signal to calculate the distance to each satellite, and applies the principle of Multilateration to determine the position.

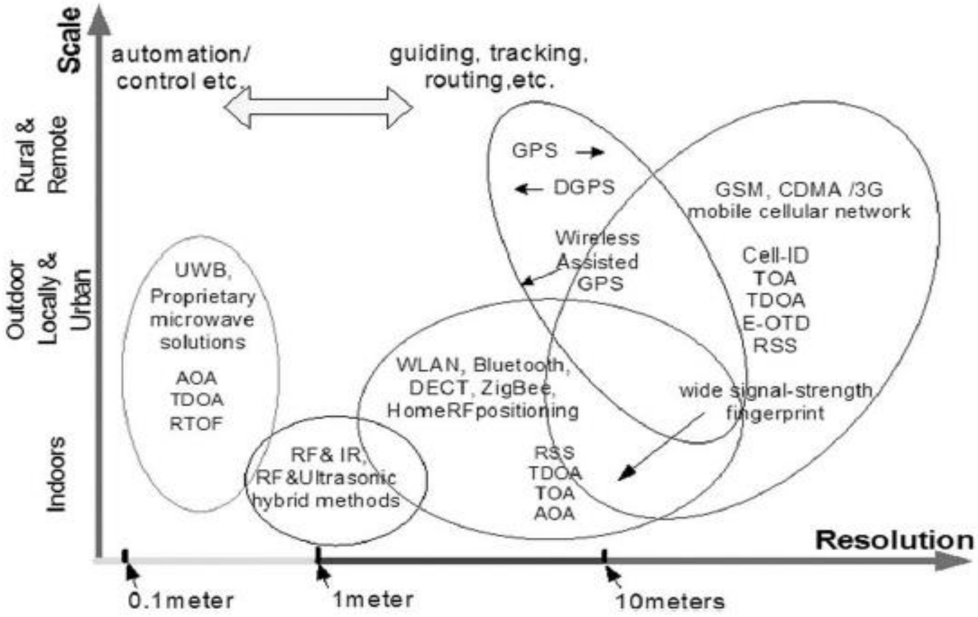


Figure 1: Outline of current wireless-based positioning systems [5].

GPS have been used in resources investigation, transportation navigation and monitoring, electronic mapping, and military operations. A GPS system mainly consists of GPS satellite constellation, ground control network, and user equipment (often called GPS receivers). There are two levels of service, namely, a standard positioning service (SPS) for general civil use; and a precise positioning service (PPS) for military use which demands higher position accuracy. While GPS works well outdoors, it performs poorly or even cannot work in indoor environments. This is because the radio signals are blocked by buildings, and thus the transient time of light is rather difficult and costly to measure , that leads to poor coverage of satellite signal for indoor environments decreases its accuracy and makes it unsuitable for indoor location estimation.

1.2.2. Cellular-Based

A number of systems have used Global System of Mobile/Code Division Multiple Access (GSM/CDMA) Mobile Cellular Network to estimate the location of outdoor mobile clients. However, the accuracy of the method using cell-ID or Enhanced Observed Time Difference (E-OTD) is generally low (in the range of 50–200 m), depending on the cell size. Generally speaking, the accuracy is higher in densely covered areas (e.g., urban places) and much lower in rural environments [7].Indoor positioning based on mobile cellular network is possible if the building is covered by several base stations or one base station with strong RSS received by indoor mobile clients. *Otsasen et al.*, presented a GSM-based indoor localization system in [8]. Their key idea that makes accurate GSM-based indoor localization possible is the use of wide signal-strength fingerprints.

The wide fingerprint includes the six strongest GSM cells and readings of up to 29 additional GSM channels, most of which are strong enough to be detected but too weak to be used for efficient communication. The higher dimensionality introduced by the additional channel dramatically increases localization accuracy. They present results for experiments conducted on signal-strength fingerprints collected from three multifloor buildings using weighted kNN technique. The results show that their indoor localization system can differentiate between floors and achieve median within-floor accuracy as low as 2.5 m. The same method could be applied in IS-95 CDMA and 3G mobile network.

1.2.3. Ultra-Wide Band (UWB)

UWB is based on sending ultra-short pulses (typically<1 ns), with a low duty cycle (typically 1: 1000). On the spectral domain, the system, thus, uses an UWB (even >500 MHz wide). UWB location has the following advantages [9]. Unlike conventional RFID systems, which operate on single bands of the radio spectrum, UWB transmits a signal over multiple bands of frequencies simultaneously, from 3.1 to 10.6 GHz.

UWB signals are also transmitted for a much shorter duration than those used in conventional RFID. UWB tags consume less power than conventional RF tags and can operate across a broad area of the radio spectrum. UWB can be used in close proximity to other RF signals without causing or suffering from interference because of the differences in signal types and radio spectrum used. UWB short duration pulses are easy to filter in order to determine which signals are correct and which are generated from multipath. At the same time, the signal passes easily through walls, equipment and clothing. However metallic and liquid materials cause UWB signal interference. Use of more UWB readers and strategic placement of UWB readers could overcome this disadvantage. Short-pulse waveforms permit an accurate determination of the precise TOA and, namely, the precise TOF of a burst transmission from a short-pulse transmitter to a corresponding receiver [10] UWB location exploits the characteristics of time synchronization of UWB communication to achieve very high indoor location accuracy (20cm).So it is suitable for high-precision real-time 2-D and 3-D location.3-D location positioning can be performed by using two different measuring means: TDOA, which is measuring the time difference between a UWB pulse arriving at multiple sensors, and AOA. The advantage of using both means in conjunction is that a location can be determined from just two sensors decreasing the required sensor density over systems that just use TDOA. To date, several UWB precision localization systems have been fielded [11] [12]. More UWB knowledge and products are given in Ref. [13] [14].

Microwave frequency, covered by the UWB frequency band, is used in Siemens local position radar (LPR) [15]. Siemens LPR is an RTOF system, in which the RTOF between a transponder unit and measuring units/base stations is measured via the frequency modulated continuous wave (FMCW) radar principle. It was launched for industrial applications like crane and forklift positioning. It is applicable only for LOS environment.

1.2.4. WLAN (IEEE 802.11)

This midrange Wireless Local Area Network (WLAN) standard, operating in the 2.4-GHz Industrial, Scientific and Medical(ISM) band, has become very popular in public hotspots and enterprise locations during the last few years. With a typical gross bit rate of 11, 54, or 108 Mbps and a range of 50–100 m, IEEE 802.11 is currently the dominant local wireless networking standard. It is, therefore, appealing to use an existing WLAN infrastructure for indoor location as well, by adding a location server. The accuracy of typical WLAN positioning systems using RSS is approximately 3 to 30 m, with an update rate in the range of few seconds.

Bahl et al. [16] proposed an in-building user location and tracking system RADAR, which adopts the nearest neighbor(s) in signal-space technique, which is the same as the *k*NN. The authors proposed two kinds of approaches to determine the user location. The first one depends on the empirical measurement of access point signal strength in offline phase. By these experiments, it is reported that user orientations, number of nearest neighbors used, number of data points, and number of samples in real-time phase would affect the accuracy of location determination. The second one is signal propagation modeling. Wall Attenuation Factor (WAF) and Floor Attenuation Factor (FAF) propagation model is used, instead of Rayleigh fading model and Rician distribution model, which are used in outdoor situation. WAF takes into consideration the number of walls (obstructions). The accuracy of RADAR system is about (2–3)m. In their following work [17], RADAR was enhanced by a Viterbi-like algorithm. Its result is that the 50 percentile of the RADAR system is around (2.37–2.65)m and its 90 percentile is around(5.93–5.97) m.

Horus system [18], [19] offered a joint clustering technique for location estimation, which uses the probabilistic method described previously. Each candidate location coordinate is regarded as a class or category. In order to minimize the distance error, location *Li* is chosen while its likelihood is the highest. The experiment results show that this technique can acquire an accuracy of more than 90% to within 2.1 m. increasing the number of samples at each sampling location could improve its accuracy because increasing the number of samples would improve the estimation for means and standard deviations of Gaussian distribution.

Roos*et al.* [20] developed a grid-based Bayesian location-sensing system over a small region of their office building, achieving localization and tracking to within1.5 m over 50% of the time. Nibble [21], one of the first systems of this generation, used a probabilistic approach (based on Bayesian network) to estimate a device's location.

Battiti et al. [22] , proposed a location determination method by using neural-network-based classifier. They adopted multilayer perceptron (MLP) architecture and one-step secant (OSS) training method. They chose the three-layer architecture with three input units, eight hidden layer units, and two outputs, since this architecture could acquire the lowest training and testing error, and it is less sensitive to the "overfitting" effect. Hey reported that only five samples of signal strengths in different locations are sufficient to get an average distance error of 3m. Increasing the number of training examples helps decrease the average distance error to 1.5 m. The authors in [21], compared the neural-networks-based classifier with the nearest neighbor classifier and probabilistic method. It is reported in [21] that neural networks give an error of 1 m with 72%probability.

Wireless location-sensing is actually a specialized case of a well-studied problem in mobile robotics, that of robot localization determining the position of a mobile robot given inputs from the robot's various sensors (possibly including GPS, sonar, vision, and ultrasound sensors). While most systems based on WLAN are using signal strength, AeroScout (formerly BlueSoft) [23] uses 802.11-based TDOA location solution. It requires the same radio signal to be received at three or more separate points, timed very accurately (to a few nanoseconds) and processed using the TDOA algorithm to determine the location.

1.2.5. Bluetooth (IEEE 802.15)

Bluetooth operates in the 2.4-GHz ISM band. Compared to WLAN, the gross bit rate is lower (1 Mbps), and the range is shorter (typically 10–15 m). On the other hand, Bluetooth is a "lighter" standard, highly ubiquitous (embedded in most phones, personal digital assistants (PDAs), etc.) and supports several other networking services in addition to IP. Bluetooth tags are small size transceivers. As any other Bluetooth device, each tag has a unique ID. This ID can be used for locating the Bluetooth tag [24]. The Blue Tags tag is a typical Bluetooth tag.

1.2.6. The IEEE 802.15.4 / ZigBee

The Zigbee is a wireless communication standard for wireless sensor networks. The Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 low-rate wireless personal area network (LR-WPAN) standard is the first open standard designed for wireless sensor networks. Promoted by the ZigBee Alliance [25], an industry consortium, it is a flexible standard suitable for many network topologies and wireless sensor applications, and includes many features designed to enable low power consumption and low-cost implementation. It's a low-cost, low-power, wireless mesh network standard. The low cost allows the technology to be widely deployed in wireless control and monitoring applications. Low power usage allows longer life with smaller batteries [26]. Mesh networking provides high reliability and more extensive range. ZigBee chip vendors typically sell integrated radios and microcontrollers with between 60 KB and 256 KB flash memory. ZigBee operates in the industrial, scientific and medical (ISM) radio bands: 868 MHz in Europe, 915 MHz in the USA and Australia and 2.4 GHz in most jurisdictions worldwide. Data transmission rates vary from 20 Kb/second in the 868 MHz frequency band to

250 kilobits/second in the 2.4 GHz frequency band. The ZigBee network layer natively supports both star and tree typical networks, and generic mesh networks. Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level. ZigBee builds upon the physical layer and media access control defined in IEEE standard 802.15.4 (2003 version) for low-rate WPANs. The specification goes on to complete the standard by adding four main components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favor total integration [27].

Besides adding two high-level network layers to the underlying structure, the most significant improvement is the introduction of ZDOs. These are responsible for a number of tasks, which include keeping of device roles, management of requests to join a network, device discovery and security. ZigBee is not intended to support power line networking but to interface with it at least for smart metering and smart appliance purposes. Because ZigBee nodes can go from sleep to active mode in 30ms or less, the latency can be low and devices can be responsive, particularly compared to Bluetooth wake-up delays, which are typically around three seconds. Because ZigBee nodes can sleep most of the time, average power consumption can be low, resulting in long battery life.

1.2.7. The Cricket system

Cricket system is an indoor localization system, which uses inexpensive wireless sensor nodes mounted at known positions. These nodes act as active beacons and transmit a pair of RF and ultrasonic signals. A Cricket node mounted on the target object, receives these signals from various beacons and applies TDoA based distance ranging. Since the atmospheric temperature has a significant influence to the speed of sound, the distance estimates obtained through the TDoA scheme must be calibrated to the ambient temperature conditions as described in the earlier section on Data Calibration. These distances are then used to find the spatial position of the object using lateration. Cricket system is able to determine the location of the target object within a few centimeters of accuracy.

It consists of location beacons that are attached to the ceiling of a building, and receivers, called listeners, attached to devices that need location. Each beacon periodically transmits its location information in an RF message. At the same time, the beacon also transmits an ultrasonic pulse. The listeners listen to beacon transmissions and measure distances to nearby beacons, and use these distances to compute their own locations. This active-beacon passive-listener architecture is scalable with respect to the number of users, and enables applications that preserve user privacy [28].

***During** the limitations of the cricket system, there are the different constraints posed by the Cricket system:*

- Cricket nodes work correctly only if a LoS path between a listener and a beacon node exists. In many sparsely deployed cases, this results in localization blind spots.
- Cricket nodes have a limited range of approximately 11m. The range depends upon the sensitivity of the ultrasonic receiver module, the detection threshold and most importantly on the power level of the transmitted ultrasonic pulse.
- Cricket distance ranging error increases as the actual distance between the listener and the beacon node is increased. The error also grows-up if the angle between the faces of listener and the beacon nodes increases. This has to do with the radiation characteristics of the ultrasonic transmitter and receiver. Beyond certain angles at a particular distance, Cricket nodes cannot compute distance estimates. The coverage over higher angles is limited to smaller distances [29] [30].

The localization performance of the Cricket system is dominated by the performance of the deployed ultrasonic sensors and their directivity and gain characteristics. When beaconing and listening nodes are faced directly to each other, the system can work properly up to 10 or 11 m. However, if the angle between beaconing and listening nodes increases, the measurements get worse and worse before it ceases to work at all. The larger the angle, the smaller is the operating range of the Cricket system. Near this limit of the maximum operating range, the measurements also get less stable and less accurate. However, for shorter distances, the system provides accurate and reliable distance measurements.

1.2.8. RFID Technology

RFID is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit and is now being seen as a means of enhancing data handling processes [31]. An RFID system has several basic components, including a number of RFID readers, RFID tags, and the communication between them. The RFID reader is able to read the data emitted from RFID tags. RFID readers and tags use a defined RF and protocol to transmit and receive data. RFID localization is similar to WLAN localization in principle. It typically employs the RF signal strength, instead of time-of-arrival of signal, as an indicator of distance. Its main advantage over the WLAN technique is the easiness of deployment RFID tags are portable and do not require cables for communication. Due to the nature of RF signals, the algorithms developed for WLAN localization are also suitable for RFID localization [32]. In this dissertation, we provide an overview of RFID system, Technique and applications with a focus on the RFID localization covered in the other chapters of this dissertation.

Some of the various positing wireless system are compared in ***Table.1,*** according to used Indoor, outdoor, technology, algorithm, accuracy, range, complexity, robustness and cost.

1.3. Wireless Sensor Network Localization

Localization (location estimation) capability is essential in most WSN applications and is a crucial issue in wireless sensor networks as it provides support for different types of location-aware applications [33]. In environmental monitoring applications such as animal habitat monitoring, bush fire surveillance, water quality monitoring and precision agriculture, the measurement data are meaningless without an accurate knowledge of the location from where the data are obtained. Moreover, the availability of location information may enable a myriad of applications such as inventory management, intrusion detection, road traffic monitoring, health monitoring, reconnaissance and surveillance. WSNs localization techniques are used to estimate the locations of the sensors with initially unknown positions in a network using the available *a priori* knowledge of positions of a few specific sensors in the network and inter-sensor measurements such as distance, time difference of arrival, angle of arrival and connectivity. Sensors with the *a priori* known location information are called *anchors* and their locations can be obtained by using a GPS, or by installing anchors at points with known coordinates, etc. In applications requiring a global coordinate system, these anchors will determine the location of the sensor network in the global coordinate system. In applications where a local coordinate system suffices (e.g., in smart homes, hospitals or for inventory management where knowledge like in which room a sensor is located is sufficient), these anchors define the local coordinate system to which all other sensors are referred, because of constraints on the cost and size of sensors, energy consumption, implementation environment (e.g., GPS is not accessible in some environments) and the deployment of sensors (e.g., sensors may be randomly scattered in the region), most sensors don't know their own locations. These sensors with unknown location information are called *non-anchor* nodes and their coordinates need to be estimated using a sensor network localization algorithm. In some other applications, e.g., for geographic routing in WSNs, where there are no anchor nodes and also knowledge of the physical location of a sensor is unnecessary, people are more interested in knowing the position of a sensor *relative* to other sensors. In that case, sensor localization algorithms can be used to estimate the relative positions of sensors using inter-sensor measurements. The obtained estimated locations are usually a reflected, rotated and translated version of their global coordinates. Based on the approach of processing the individual inter-sensor measurement data, localization algorithms can be broadly classified into two categories: centralized algorithms and distributed algorithms. In centralized algorithms, all the individual inter-sensor measurements are sent to a single central processor where the estimated locations of non-anchor nodes are computed; while in distributed algorithms each node (or a group of nodes in close proximity to each other) estimate its (their) own location(s)using inter-sensor measurements and the location information collected from its (their) neighbours. Major approaches for designing centralized algorithms include MDS, linear programming and stochastic optimization approaches.

Table 1 : Over view of comparison of various positing wireless system .

Wireless system	**Outdoor**	**Indoor**	**Real time**	**Wireless technology**	**Localization Algorithm**	**Range**	**Accuracy**	**Complexity**	**Robust**	**Cost**
Microsoft RADAR	*	*	*	WLAN, RSS	kNN, Viterbi like algorithm	Indoor	3-5 m	Moderate	Good	Low
Horus		*	*	WLAN, RSS	Probabilistic method	Indoor	2m	Moderate	Good	Low
WhereNet			*	UHF TDOA	Least Square/RWGH	Indoor	3-5 m	Moderate	Good	Low
GPS	*		*	RF, TOF	Lateration	global	5m	Moderate	Good	High
Cricket		*	*	Ultrasound+ RF(418MHz) ,TOF	Lateration	10m	1-3 cm	Moderate	Good	Low
UWB		*	*	TOA	Proximity	15m	10cm	Moderate	Good	Medium
SPOT ON		*	*	Active RFID RSS	Ad-Hoc Lateration	Depends on Cluster size Medium	3m	Moderate	Good	Low
Landmark		*	*	Active RFID RSS	kNN	Indoor	Less than 2m	Poor	Medium	Low
GSM Fingerprinting	*		*	GSM Cellular Network	Weighted kNN	outdoor	50m	Moderate	Good	Medium
Bluetooth		*	*	RSS, unique ID.	Proximity	15 m	range	Moderate	Moderate	Low
Aero Scout			*	TOF Triangulation (TDOA for absolute location; RSSI for symbolic location)		Building/ local area	1-5m	Moderate	Good	Medium
RFID		*	*	RSS	triangulation	Indoor	range	Moderate	Good	Medium

Centralized and distributed distance-based localization algorithms can be compared from several perspectives, including location estimation accuracy, implementation and computational complexities, and energy consumption.

Distributed localization algorithms are generally considered to be more computationally efficient and easier to implement in large scale networks. However in certain networks where centralized information architecture already exists, such as road traffic monitoring and control, environmental monitoring, health monitoring, and precision agriculture monitoring networks, the measurement data of all the nodes in the network need to be collected and sent to a central processor unit. In such a network the individual sensors may be of limited computational capability, it is convenient to piggyback localization related measurements to other measurement data and send them together to the central processing unit. Therefore a centralized localization algorithm appears to be a natural choice for such networks with existing centralized information architecture.

In terms of location estimation accuracy, centralized algorithms are likely to provide more accurate location estimates than distributed algorithms. One of the reasons is the availability of global information in centralized algorithms [34].

In principle any radio device can be used for positioning but practical demands leave us only few alternative solutions. In many cases GPS has made local positioning systems useless due to its increasing accuracy and reliability. However, even today GPS does not work properly indoors because of the needed satellite connection. This can be solved to some extent by using pseudo satellites that imitate real satellites. Also GPS and other active localization techniques require actively powered devices that cannot be minimized in size very far. For the above reasons, we also need other positioning methods in local environments even if they are more expensive and more difficult to implement. RFID is designed, by definition, to provide wireless object identification. It is developing fast and has become the industry standard for logistic and passport identification. RFID tags are usually very small, especially the passive ones, and are easy to mount on an animal. The reading distance is enough for indoor use and RFID tags are very cheap [35].

In RFID systems, location information is of great importance to provide location aware services combined with identification. Conventional RFID systems can only provide coarse localization information.

1.4. Positioning Principles for Indoor Wireless Networks

Radio propagation in indoor environment is subject to numerous problems such as severe multipath, rare line-of-sight (LoS) path, absorption, diffraction, and reflection [36]. Since signal cannot be measured very precisely, several indoor localization algorithms have been presented in the dissertation. They can be classified in three families: distance estimation, scene analysis, and proximity.

1.4.1. Distance Estimation

This family of algorithms uses properties of triangles to estimate the target's location. The triangulation approach, it is common under the term angulation, illustrated in ***Fig.2***, consists in measuring the angle of incidence (or Angle of Arrival, AOA) of at least two reference points. The estimated position corresponds to the intersection of the lines defined by the angles. It can estimate distance to source ***S*** by using simple trigonometry formula.

On the contrary, the lateration approach, illustrated in ***Fig.3***, estimates the position of the target by evaluating its distances from at least three reference points. Since Trilateration is the process of distance based lateration to find a point from the premeasured distances, and applies the distance information between signal receiver and source. When the localization system knows at least a set of three distances from different receiver, the system can draw three circles, and the radius of a circle is the measured distance, and the center is the known signal receiver's position. The intersection of three circles will be the expected signal source's location. However, there is one restrictive condition such as the three of signal receivers cannot place in a single straight line for calculation of trilateration. The range measurements techniques use Received Signal Strength (RSS), Time of Arrival (TOA), Time Difference of Arrival (TDOA), or Received Signal Phase (RSP), We refer to [37] for more detailed discussions on the RSP. In the chapter three, we shall give a more detailed discussion of RSS, TOA and TDOA in the range measurements techniques.

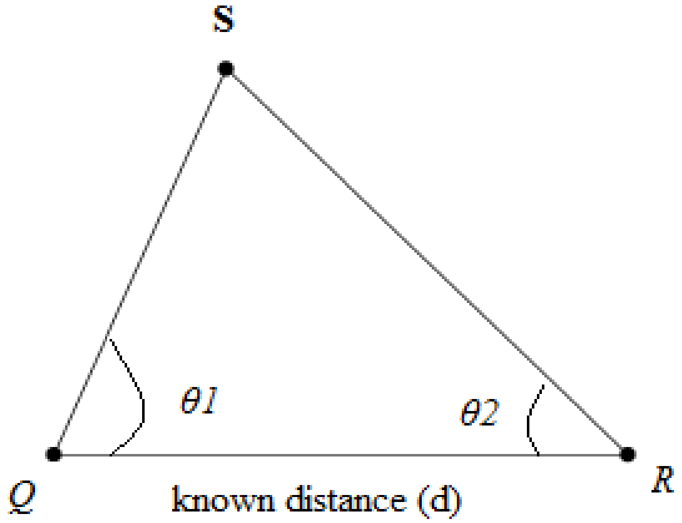


Figure 2: Triangulation, the estimated location is calculated with the angles formed by two- ref. & the target nodes

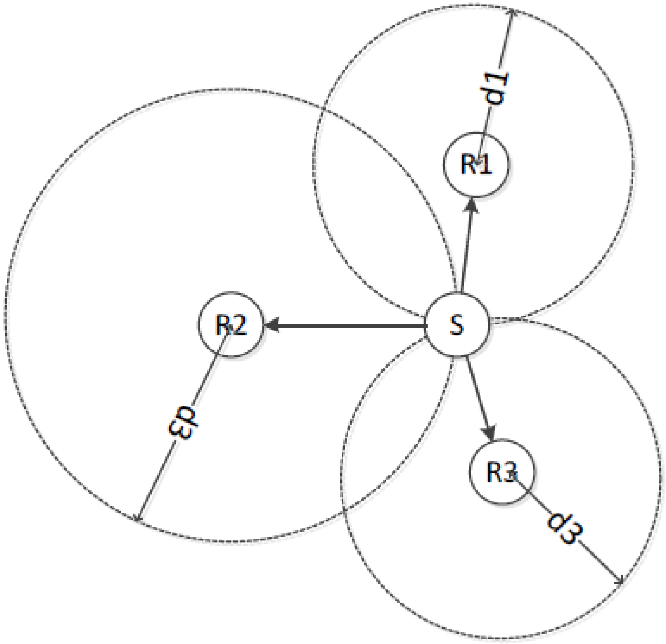


Figure 3: Trilateration, the estimated location corresponds to the intersection point of three circles.

1.4.2. Scene Analysis

Scenes analysis approaches are composed of two distinctive steps. First, information concerning the environment (fingerprints) is collected. Then, the target's location is estimated by matching online measurements with the appropriate set of fingerprints. Generally, RSS-based fingerprinting is used. The two main fingerprinting-based techniques are: k-nearest neighbor (kNN) also known as radio map, and probabilistic methods. We refer to [38] [39] for more detailed discussions on these methods respectively.

1.4.3. Proximity

The last type of localization techniques in indoor environments is based on proximity. As shown in ***Fig.4,*** proximity method uses the approximate communication area to detect whether the target node is in a region or not. The method requires less computation than Bayesian inference. In other words, it relies on dense deployment of antennae. When the target enters in the radio range of a single antenna, its location is assumed to be the same that this receiver. When more than one antenna detects the target, the target is assumed to be collocated with the one that receives the strongest signal. This approach is very basic and easy to implement object localization. RFID, pressure sensor, or Infra-Red based localization systems commonly used proximity approach. However, the accuracy is on the order of the size of the cells [40] [41].

Recent advances in ubiquitous computing have necessitated RFID-based object localization capabilities, with research efforts specifically targeting the positioning of object tags. When numerous ubiquitous computing applications depend on the ability to locate objects as a key functionality. It show that RFID technology can be leveraged to achieve object localization in an inexpensive, reliable, flexible, and scalable manner, and RFID-based localization techniques can be broadly classified as reader and tag-based approaches. Existing RFID object localization techniques are described below.

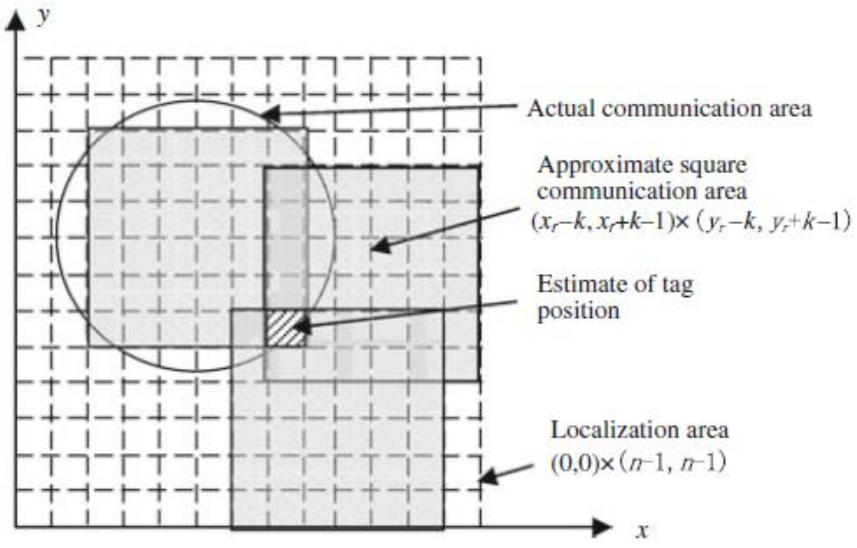


Figure 4: Schematic of proximity method [40].

LIONEL M. et al in paper [38] *:* have presented LANDMARC, a location sensing prototype system that uses Radio Frequency Identification (RFID) technology for locating objects inside buildings. The major advantage of LANDMARC is that it improves the overall accuracy of locating objects by utilizing the concept of reference tags. This system is an active RFID locating system using scene analysis. It requires reference tags to be deployed at known positions. RSS measurements from multiple readers are used to locate the target RFID tag using the locations of the *k* nearest reference tags. Different weights are imposed on the *k* nearest reference tags to estimate the location of the target tag. In the LANDMARC system, dense deployments of reference tags are necessary for good performances this system is based on the kNN technique. Reference tags which are fixed tags with known positions are deployed regularly on the covered area. Readers have eight different power levels. We refer to [42] [43] for more detailed discussions on the LANDMARC system

Yiyang Z. et al in paper [44]*:* VIRE uses the principle of LANDMARC, which is 2D regular grid of reference tags. Nevertheless, this method introduces the concept of proximity map. The whole sensing area is divided into regions where the center of each region corresponds to a reference tag.

Jeffrey H. et al in paper SpotON [45]*:* have created of SpotON, a new tagging technology for three dimensional location sensing based on radio signal strength analysis. It's a RFID location sensing system which belongs to the family of distance estimation. SpotON uses RSS measurements from long range active RFID tags to approximate the distances between tags and readers. Multiple readers collect the RSS measurements and then transform the RSS measurements into distance estimations through a function defined with empirical data. Multilateration is then applied to calculate the positions of the tags.

Chong W. et al in paper [46]*: have* proposed two positioning schemes, namely, the active scheme and the passive scheme. This method is also based on the deployment of reference tags. It requires that the *readers* have *K* transmission power levels. For the localization of a tag, the readers start with the lowest power level and gradually increase the transmission power until they receive the response from the tag.

Abdelmoula B. et al in paper [39] : have introduced a new positioning algorithm for RFID tags using two mobile RFID readers and landmarks which are passive or active tags with known location and distributed randomly. This approach also utilizes reference tags. The first step consists in calculating with RSS measurements from two readers the distance between each reference tag and the target tag. The location of the tag is obtained by solving with the minimum mean squared error algorithm.

ElifAydın et al in paper [47]*:* have introduced a study on localization and tracking of an object carrying an active RFID tag. The study incorporates processing of the signals received from transmitters, in a way to locate and track the coordinate in an indoor environment. Bayes Decision Rule in Location Estimation Bayes Theorem is essentially an expression of conditional probabilities. In the framework of estimating the position of RFID tag, an observation vector is formed by received radio signal strengths, transmitted from the three transmitters at distinct frequencies in UHF band.

Manzoor F. et al in paper [48]*:* have presented an algorithmic approach to locate an unknown RFID tag with the use of multiple passive RFID tags. A number of experimental results indicate a general reduction of linear positioning error mean with respect to decreasing inter-tag spacing from a maximum of 7m to a minimum of 1m, respectively. The main advantage of this technique is the reduction in number of expensive RFID readers; instead multiple inexpensive passive RFID tags placed at calculated positions provide essential data to position an unknown tag.

1.6. Motivation and Objective

During the last decade with the rapid increase in indoor wireless communications, location-aware services have received a great deal of attention for commercial, public-safety, and a military application, the greatest challenge associated with indoor positioning methods is moving object data and identification. In order to reduce administration time and more importantly keep status by storing a full academic record, we present the Identification of Employees in National Technical University in Athens (IE-NTUA). When the employees access to a certain area of the building (enters and leaves to/from a building), Radio Frequency Identification (RFID) applied for identification by offering special badges containing RFID-tags.

On the other hand, localization is an important aspect in the field of wireless sensor networks that has attracted significant research interest recently. The interest in wireless sensor network localization is expected to grow further with the advances in the wireless communication techniques and the sensing techniques, and the consequent proliferation of wireless sensor network applications.

The fundamental problem of position can be formulated as that of finding or estimating the location, in a two-dimensional (2D) or three-dimensional(3D) space of a point of interest within a coordinate system constructed (for LANDMARC uses some known references. In general location scenarios, and at the point of interest, a new location is determined bearing in mind the displacement from a previously known reference location. This may imply some direction and inertial estimation. Due to the widespread penetration of wireless systems, we consider RFID-tags with transmission or reception capabilities that somehow assist in the location procedure.

Many radio-based positioning systems use the observed signal strength as an indicator of distance from a radio source. MDS method only using distance information between tag to reader distances from the received signal strength measurement, and inter tags distances based on the tag-to-reader distance information.

Radio propagation in indoor environments is complicated by the fact that the shortest direct path between the transmitter and the receiver is usually blocked by the walls, ceilings or other objects in an interior space. Hence, the signal power is distributed over a multiplicity of paths of various strengths between the transmitter and the receiver. The length of the paths is dependent on the architecture of the environment and the locations of the objects found in the vicinity of the transmitter and the receiver.

According to this property, we present the effect of propagation parameters on the localization accuracy by varying these parameters to observe the probability distribution of estimated distance, where the propagation parameters in indoor environments make working with signal strength measurements challenging. Then we model the ratio of the effect path loss on the received signal strength for RFID tags, which are distributed in coverage area to alleviate the measurement error on the location estimation. The proposed model based on knowledge the effect of path loss on the received strength for RFID tags in order to measure the received signal, which has Maximum RSS relative *to Minimum PL(Max RSSPL),* which leads to measure the minimum distance between transmitter and receiver, that is caused by non-linear relationship between the signal strength and the distance. After that we introduce the MDS algorithm which is to construct the distance matrix as the input to estimate the RFID tag positions. The goal of this work is to reduce the distance between the estimated and the actual RFID tags position in order to reduce the localization error and increase the localization accuracy of our technique.

1.7. Organization

This dissertation consists of six chapters. It begins with an introductory chapter that covers the basic principles of techniques involved in the design and implementation of wireless sensor network localization systems, outlined the wireless sensor networks localization. A focus of the chapter is on explaining the Positioning Principles for Indoor Wireless Networks and presents the existing RFID object localization. The other chapters are organized as,

In Chapter two, we present the structure and the application of RFID technology has been introduced.

In Chapter three, we describe the characteristic of the Ranging Technology in the theoretical part.

In chapter four we present our localization algorithm to locate RFID tags based on multidimensional scaling (MDS). We then give the motivations and objective algorithm in detail. After that we describe the MDS algorithm, followed by the performance evaluation via simulation.

In chapter five we present the identification of employees in national technical university of Athens, and also in the same chapter provided the indoor simulation results to observe the characteristic and performance evaluation of the localization algorithms which is described in the theoretical part. Moreover, concludes all the results of simulations conducted throughout this dissertation and future work are given in Chapter Six.

2o ΚΕΦΑΛΑΙΟ

CHAPTER TWO

II

This chapter provides fundamental knowledge regarding a RFID system technology in the following order. First we introduce the RFID background and Basic principle of RFID system, RFID Frequency Bands, then tag technology and classification, last Data Transfer between a Tag and a Reader is introduced.

2.1. RFID Background

The inventors of RFID technique were Englishmen, who developed this system during the Second World War. The idea was to discern their own aircraft from the enemy aircrafts that were coming from France to Britain. To achieve their goal they attached transponders to the aero plane, which could send back the correct answer if the airport sent desiring signals. This British technique was called Identification Friend-or-Foe (IFF) system, and like other techniques this system was the ground for the RFID technique. These developing projects were that time strictly for military purposes. This technology is the basis for the world’s air traffic control systems today. The first commercial applications of RFID were developed in the end of 1960’s and 1970’s when the Electronic Article Surveillance (EAS) systems were introduced. EAS equipment was developed to protect inventory items such as clothing in department stores. They were designed to start an alarm when they came near a reader. These systems says to be used a primitive type of transponders where each transponder contains same information. As the time goes by the technique becomes cheaper especially because of the cheap transponders due to compact and cost-effective technologies, for example IC and the microprocessor. In 1970’s development began to speed up when these RFID applications were used in different areas. RFID is an enabling technology for remotely identifying, monitoring, and tracking various objects of interest using radio wave transmissions. The automatic identification of objects is possible by wireless communications between a tag (attached to an object) and its reader (interrogator) at a distant location. RFID remote monitoring can range from detecting the presence and absence of an object to tracking its movement over short or long distances [49] [50].

- One or more tags or transponders with unique identification codes and a small antenna embedded within each tag.
- A reader, or interrogator, with one or more antennas that are connected to a host computer through various kinds of interfaces such as: USB, PCMCIA, RS232, or wireless interfaces such as Bluetooth.
- Application software or middleware running on a host computer to translate the received data to user-friendly messages regarding the tagged item's presence and absence status or its location. ***Fig.5,*** represents a typical RFID system and its components [51] .

RFID is a fast and reliable technology that does not require physical contact or line-of-sight (LoS) link between the tagged items and the readers, hence it reduces the human intervention for real time tracking and monitoring of assets. In many documents, RFID is considered as a future replacement of barcodes and is referred to "a barcode that barks". Although RFID tags are more expensive than barcodes, there are certain advantages that make RFID more attractive than barcodes for a variety of applications. ***Table.2*** summarizes a comparative analysis of RFID tags versus barcodes with an advantage arrow pointing to each technology in different cases.

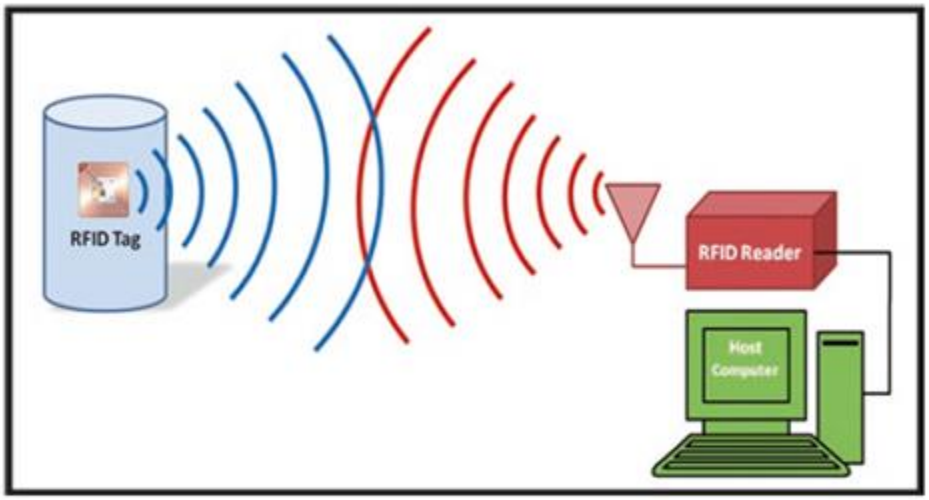


Figure 5: Figure: Components of a typical RFID system [51].

Before delving into a more detailed discussion of various RFID technologies, we will summarize several of the present and envisioned future applications of RFID:

-Tracking and identification
- Large assets, e.g. railway cars and shipping containers
- Livestock with rugged tags
- Pets with implanted tags
- Supply-chain management with EPC
- Inventory control with EPC
- Retail checkout with EPC
- Recycling and waste disposal
- Payment and stored-value systems
- Electronic toll systems
- Contact-less Credit Cards, e.g. American Express Blue card
- Stored-valued systems, e.g. ExxonMobil Speedpass
- Subway and bus passes
- Casino tokens and concert tickets
- Access control
- Building access with proximity cards
- Ski-lift passes
- Concert tickets
- Automobile ignition systems
- Anti-Counterfeiting:
- Casino tokens, e.g. Wynn Casino Las Vegas
- High-denomination currency notes,
- Luxury goods, e.g. Prada
- Prescription drugs

Furthermore, RFID as a technology houses more capabilities, features, and functions than a barcode at a higher cost.

2.2. Basic principle of RFID system

Radio Frequency Identification (RFID) is a way for automatically identification of objects with radio waves, like a barcode that uses radio waves instead of light. A RFID system has a few major components, a reader with an antenna, a tag and a data handling system, often a Personal Computer (PC) with connection to a larger network, see ***Fig.6.*** The tag is placed on the object that is to be identified. The tag contains the suitable information of the object. The reader has a number of different responsibilities like powering the tag, identify the tag, read and sometimes write data to the tag. The reader also communicates with the database in which the information from the tags will be processed.

When the object that is tagged comes in a reader's interrogation zone, reading zone, the reader sends out a radio wave to the tag which powers up and sends back its information to the reader, in some cases new information is sent from the reader to the tag, the reader sends the information to a database that processes the data from the tag in a suitable way because RFID is using radio waves it is not necessary to have free sight between the reader's antenna and the tag. The distance between the transponder and reader depends on which coupling and frequency that are used. It is possible to achieve distances from a few centimeters up to hundreds of meters. The speed which the data can be transferred between tag and reader is also depending on which frequency that is used lower frequencies can't transfer data as fast as the higher frequencies [52]. This means that if it is necessary to read many tags at the same time a higher frequency is preferred.

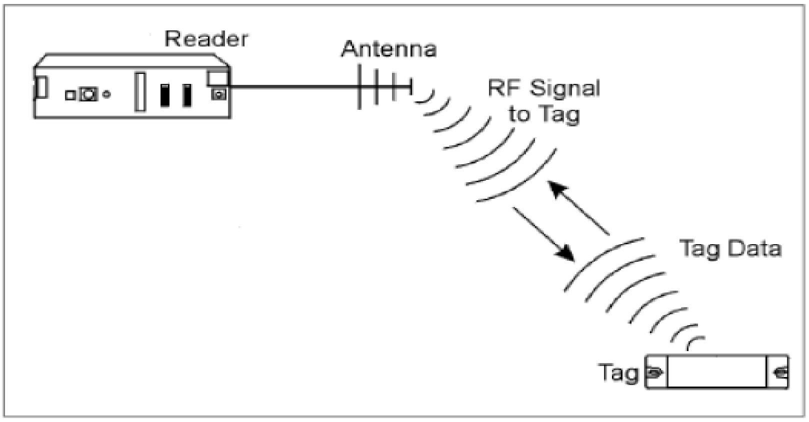


Figure 6: Basic principle of microwave RFID system [52].

2.3. RFID Technology

Radio Frequency Identification (RFID) is an Automatic Data Collection (ADC) technology that uses radio waves to transfer data between a reader and a movable item to identify, categories, and track data. Automatic Identification and Data Capture (AIDC) is the generic term of identification system including barcodes and RFID. There are various RFID technologies available today. These include Very Short Range Passive RFID, Short Range Passive RFID, Active Beacon, Two-way Active and RTLS. The reading range and frequency is highlighted in ***Table.2.***

Fig.7, depicts *RFID* system overview, where a widespread RFID system includes the following components:

- A tag, a label or a PCB (Printed Circuit Board) that is embedded with a single microchip and an antenna.
- A radio device, a reader (transceiver) that communicates with or interrogates the tag for reading and writing.
- A logical system that passes on information that lies on the tag to other systems.

The components of an RFID system do not all have to be built and supplied by the same supplier. Some only make the tags, while others make readers to read several different types of tag. Systems and standards need to be open enough to allow different suppliers to provide readers for the same tags, and similar, for different tags to be read by the same reader. Here we have chosen one way to illustrate an RFID system and its components. As shown in above Figure the RFID system consists of a tag, a reader system and an application. The tag contains a microchip, power and an antenna.

The reader system is divided into an antenna, a reader and an interface. The reader and the interface are explained later on in this dissertation. Finally the application is the logical system in an RFID system. The application can be different depending on what system it supports but the main function is to process the data that is collected by the reader.

The collected information is often sent to a database to be used by other systems in a company [53].

Table 2: Different RFID technologies.

Technology	Advantage	Disadvantage	Working Areas
Very short range Passive RFID	- Very low-cost tag - Global agreed frequency range	- Requires significant process changes - Limited Multi-tag capability	- Pet identification - Product identification
Short range Passive RFID	- Low-cost tag - Sufficient range for dock doors and similar portals	- No global frequency - Many readers/antennas required for coverage - Slow Multi-tag collection	- Personal identification system - Anti-theft systems - Wild life management
Active Beacon	- Low-cost active - Wide area monitoring	- Limited checkpoint/portal capability - No means of disabling beacon(air cargo)	- For example; a casino were the bet of a player can be tracked by a casino chip, identify high rollers and those who are losing a lot of money
Two-way Active	- High reliable communication - Support for advanced functionality	- Expensive tag - Limited checkpoint/portal capability	- Toll Collection - Traffic Management Systems - Inter modal Container Management
Real-time Locating system	- Physical finding/locating - Wide area monitoring	- Very expensive infrastructure - Precision does not support ”logical” locating	- To identify assets in large areas such as factory or distribution yard - Assets tracking

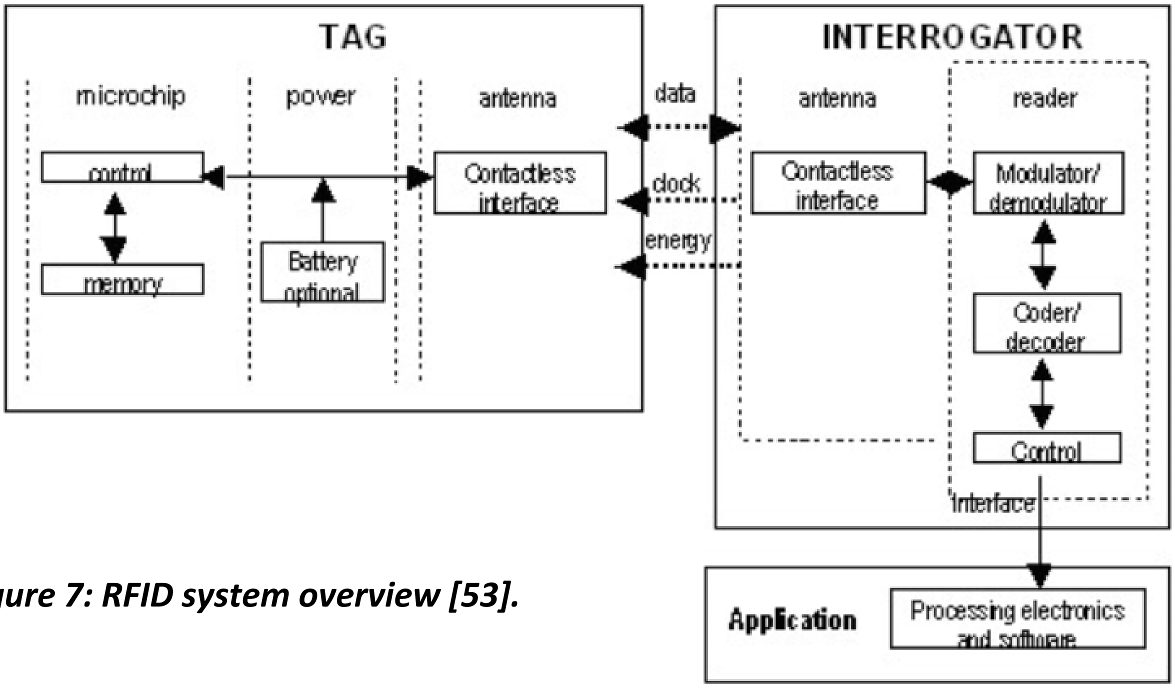


Figure 7: RFID system overview [53].

2.4. RFID Frequency Bands

The operating frequency of an RFID system directly influences, its read range and therefore its target application. ***Table.3,*** shows the four main spectral bands allocated for COTS RFID systems.

Table 3: Frequency bands used for RFID systems.

Low Frequency (LF)	**High Frequency (HF)**	**Ultra High Frequency (UHF)**	**Microwave Frequency (MW)**
125–134 KHz	13.56 MHz	868–928 MHz	2.4 GHz

2.4.1. Low Frequency (LF) Band

This frequency band covers the RF spectrum from 125–134 KHz and provides good signal penetration through a range of materials including human body or various walls and barriers. The RFID tags operating in these low frequencies have the advantage of performing well around a variety of conductive and dielectric materials such as metal, soil, and water. Therefore, LF tags are good candidates for personnel and animal tracking as well as in the automotive industry.

The LF RFID systems are less susceptible to external interference since the lower frequency bands are less crowded with radio services. Another argument to support the relatively low sensitivity of RF tags to interference at low frequencies is that such frequencies mostly include narrowband systems and the noise level seen at the input of their receivers is low.

The range expected from tags operating at low frequencies is from few centimeters to few meters depending on the size of the antennas and the sensitivity of their readers. However, the lower frequency, the larger the antenna size which causes a physical limitation for most tags in terms of size and hence the range remains in the lower limit of few centimeters for most applications. It’s important to mention that due to the antenna size limitation of RF tags for low frequencies, these tags are mainly inductively coupled, therefore their read ranges drop very fast with distance by a factor of $1/r^3$ where r is the distance between a tag and its reader. Finally, there are additional limitations to the capability of LF RFID systems for many practical applications due to their low data rate (on the order of a few bits/s) and the slow read rate. Furthermore, as one can infer from the general evolution of the technology, modern demand for such communication systems like RFID require the transmission of more information and at faster speeds [51]

2.4.2 High Frequency (HF) Band

The passive HF RFID systems operate at 13.56 MHz and are used where medium data rate (on the order of Kbps) and short read ranges (< 1 m) are sufficient for applications such as smart cards, short range item level tracking such as tracking books in libraries, etc. Their performance in the presence of water and metals are lower compared to LF tags but better than higher frequency tags such as UHF and microwave tags. The HF tags have the capacity for larger memory and faster communication speeds than the LF tags, giving them the ability to detect multiple tags at once. Furthermore, these tags have shorter wavelengths compared to LF tags, therefore, they have smaller and less expensive antennas. Similar to LF tags, the HF tags also use the inductive coupling for communications with their readers.

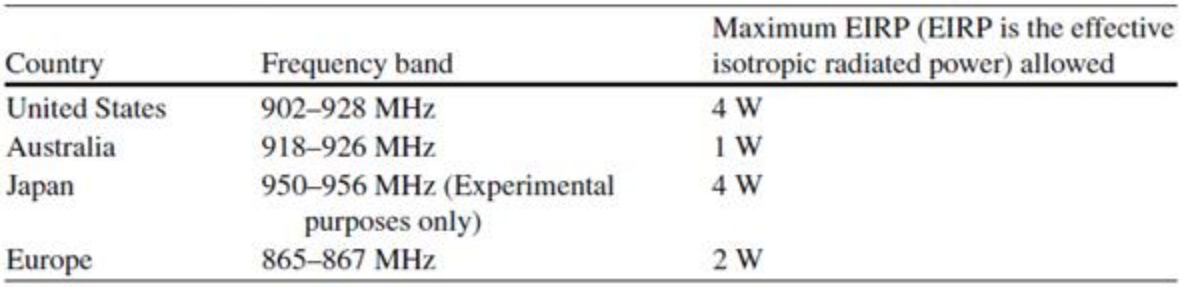
2.4.3 Ultra High Frequency (UHF) Band

RF tags operating in UHF band (868–928 MHz) use backscatter technology for their tag-reader communications where the tag reflects back the electromagnetic signal it receives from its reader. The UHF tags offer longer ranges (typically 3–10m range) and higher reading speeds, support simultaneous detection of more number of tags compared to LF and HF systems, and finally need smaller antennas.

However, the read range of these significantly deteriorates around metallic and liquid surfaces and their cost is higher than the LF and HF RFID tags. Furthermore, these tags are not global in the sense that the power level and operating frequency of UHF tags varies in different parts of the world. ***Table.4***, represents the power level and frequency of operation in different regions.

As described in ***Table.4,*** RFID systems in UHF bands have difficulty in worldwide operations. In addition, the operating frequency for these tags falls into the crowded unlicensed ISM (Industrial, Scientific, and Medical) band, making the HF tags susceptible to all kinds of electromagnetic interfering signals. The UHF tags are usually used in supply chain and asset management applications.

Table 4: UHF frequency bands and their allowed maximum EIRP for few regions of the world .



Country	Frequency band	Maximum EIRP (EIRP is the effective isotropic radiated power) allowed
United States	902–928 MHz	4 W
Australia	918–926 MHz	1 W
Japan	950–956 MHz (Experimental purposes only)	4 W
Europe	865–867 MHz	2 W

2.4.4 Microwave (MW) Band

The microwave band (2.4 GHz), *offers* high data transfer rates (Kbps) and long distances (~ 30 m) and is typically used in toll collection applications. RFID systems at this frequency band are expensive and require line of sight transmission. The reason is that in such high frequencies non-line-of-sight (NLOS) signals suffer more significantly from propagation effects such as multipath interference and signal diffraction. In addition, microwave tags do not penetrate many materials and their read performance suffers considerably from being adjacent to metals and water.

As explained earlier in this section, each of the aforementioned frequency bands offers advantages and challenges for the operation of RFID systems. The tags in lower frequency bands such as LF and HF provide better performance near metal and water than the higher frequency ones. However, their data rate is slower and they have shorter read range. The higher frequency bands provide faster speeds and longer read ranges but they suffer from higher attenuation rates, are more expensive, and require more regulatory control.

Table.5, summarizes the RFID frequency bands based on their advantages and disadvantages as well as their typical applications. The lower frequencies have better performance around metal and water, while they have lower data rates and lower speed of communications. On the other hand, the higher frequencies have longer range and higher communications speed with poor performance around metallic and liquid objects as summarized in ***Fig.8.***

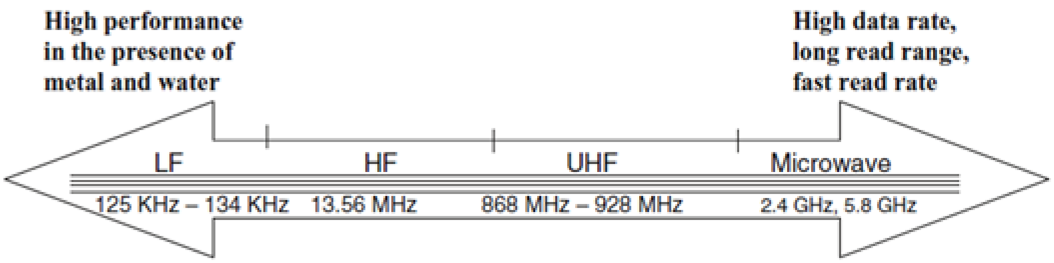
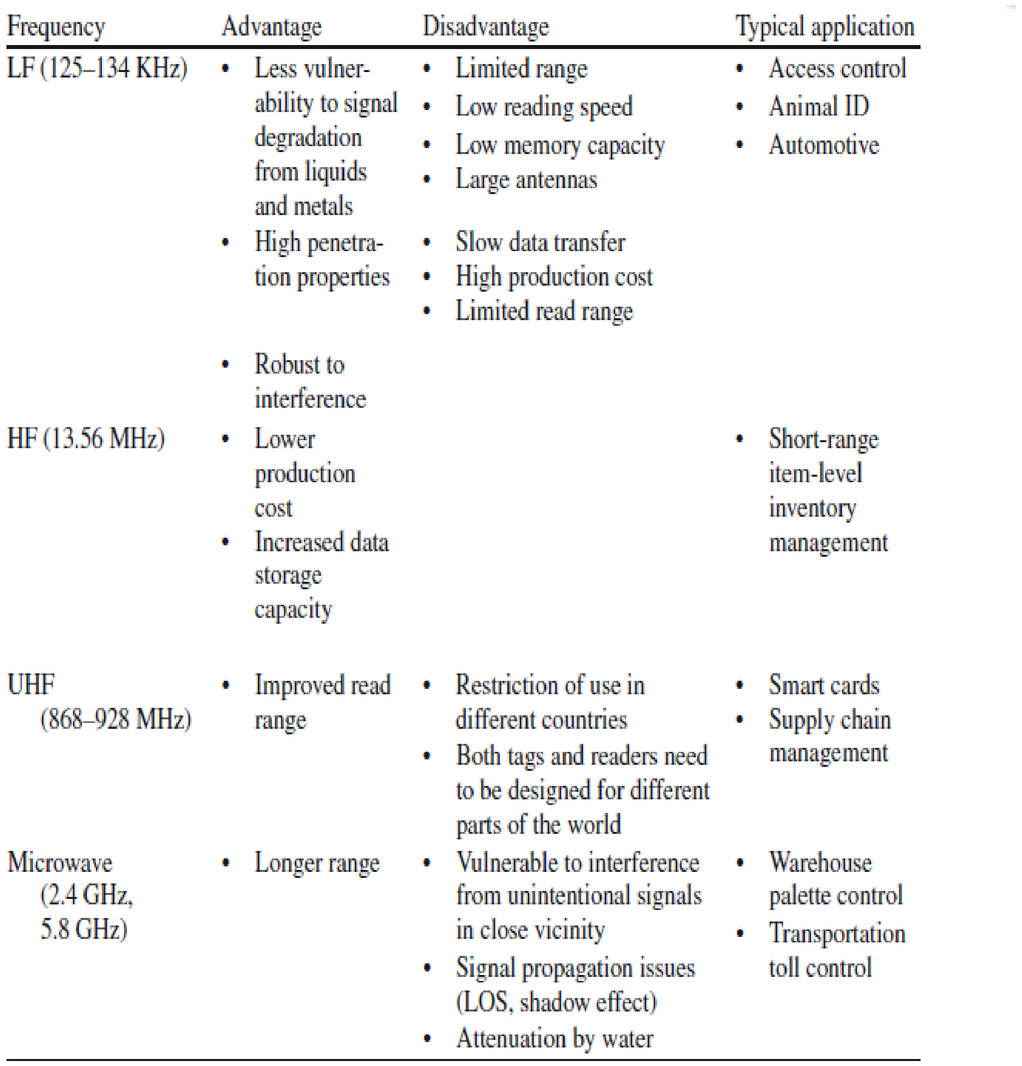


Figure 8: Portions of RF electromagnetic spectrum for conventional RFID system [51].

Table 5: Summary of RFID systems with various operating frequencies.



Frequency	Advantage	Disadvantage	Typical application
LF (125–134 KHz)	• Less vulnerability to signal degradation from liquids and metals • High penetration properties	• Limited range • Low reading speed • Low memory capacity • Large antennas • Slow data transfer • High production cost • Limited read range	• Access control • Animal ID • Automotive
HF (13.56 MHz)	• Robust to interference • Lower production cost • Increased data storage capacity		• Short-range item-level inventory management
UHF (868–928 MHz)	• Improved read range	• Restriction of use in different countries • Both tags and readers need to be designed for different parts of the world	• Smart cards • Supply chain management
Microwave (2.4 GHz, 5.8 GHz)	• Longer range	• Vulnerable to interference from unintentional signals in close vicinity • Signal propagation issues (LOS, shadow effect) • Attenuation by water	• Warehouse palette control • Transportation toll control

2.5. Tag Technology and Classification

An RFID tag is a microchip combined with an antenna system in a compact package as show in ***Fig.9***. The microchip contains memory and logic circuit to receive and send the data back to the reader. The antenna receives signal from an RFID reader and then backscatters the signal with required data [54] [55].

The RFID tags can be broadly classified in two different categories as follows:

- Based on ‘on-board’ power supply
- Based on capacity to rewrite the data

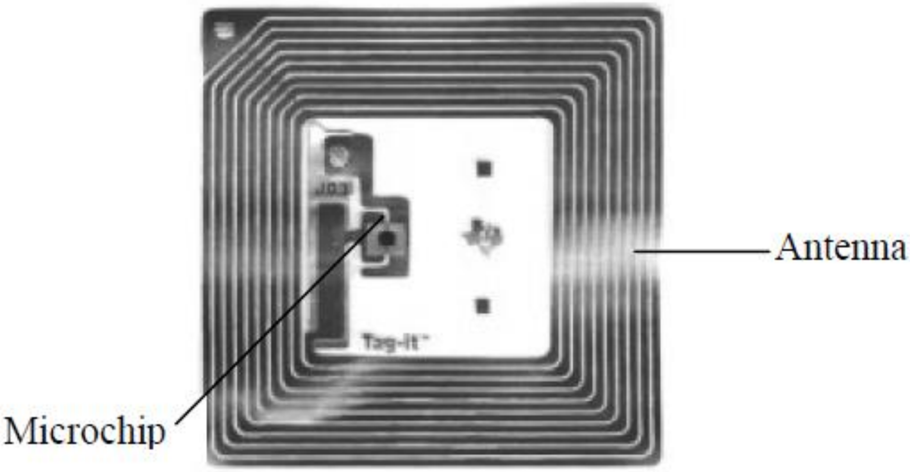


Figure 9: RFID Tag [54].

However, ***Table.6***, classifies the tag based on various parameters like identification format, frequencies, and form factors etc. There are tags available in the market, which are digestible in the human body. Theses tags are used in medical diagnosis. The tag can be classified into two or more categories viz. based on power source, based on form factor, based on operating frequency etc.

Table 6: Tag Classification Criteria

Criteria	Types
Identification format	64-Bit EPC Tag, 96-Bit EPC Tag, 128-Bit EPC Tag etc
Power Source	1. Passive 2. Semi-passive 3. Active
Frequencies	LF, HF, UHF
Functionality	1. Memory (Size, Read/Write) 2. Environmental sensors 3. Security functionality
Form Factor	1. Size/Shape of the tag 2. Digestible, implantable 3. Weight of the tag 4. The method by which the tag is affixed

In general, the RFID tags classify into passive and active categories. The passive tag has no 'on-board' power source. They extract power from the signal (CW) sent by the reader that is used to operate the chip. The absence of battery makes their size smaller. The active tag has 'onboard' power source. This 'on-board' power source is used to transmit the data from the tags to the reader, and this power is also a source for other electronics components of the tags present in the tag. In the passive tag, the reader initiates the communication whereas in active tag, the tag initiates the communication. A semipassive tag is passive in nature, but it contains a battery to supply power to auxiliary components like sensors, user interface etc. A tag generally operates in three main the choice of a particular frequency is solely govern by the type of applications and read-rang required viz. animal monitoring application requires LF whereas toll collection requires UHF. The size, shape, weight and physical nature plays very important role in selecting a tag for a particular application. If it suppose the person's digestive system then it is possible through digestive RFID tags only. These edible RFID tags can be swallowed by patient and get disintegrated in the body for diagnostic process. The characteristics of the tag depend on the communication protocol/technologies. Each tag has different data rate, read capability, memory, cost and life mentioned in ***Table.6***. Another classification that is based on the content and format of the information.

This classification is based on EPC Global standard as shown in Table.2.7, [56]. EPC Global Inc., is standardizing RFID under the name EPC. The EPC system was commercialized in 2003. The EPC organization specifies technical protocols that define how information is programmed and communicated, and also creates a data structure that defines the content of the information itself. Each tag with EPC standard contains an ID-number of typically 96 bits. This ID-number is unique and identifies each individual object, similar to a barcode. The EPC classification has potential to change the way many companies do business operations to meet the standard and allow business to share information effectively.

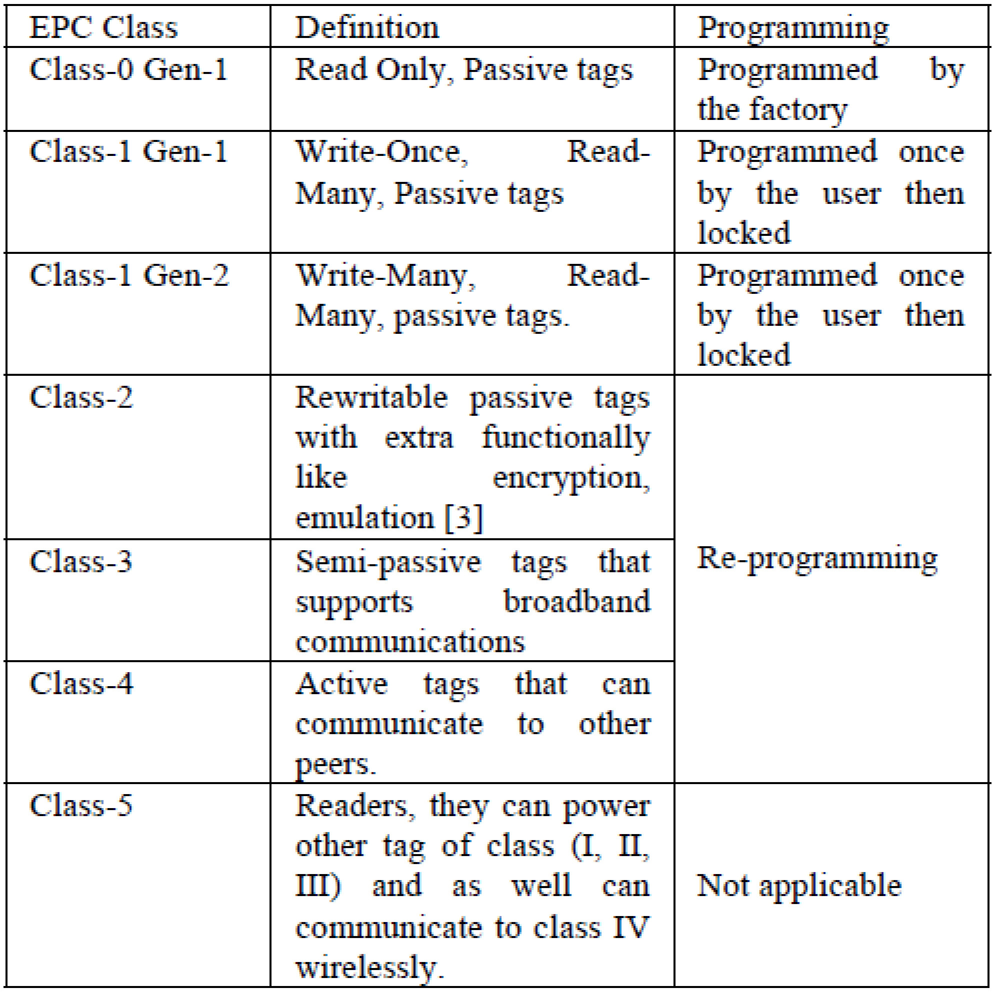
The classification of tag based on the format, read/write capability and programming capability is as shown in ***Table.7.*** The EPC classification consists of Class and Generation. The Class describes a tags basic functionality for example whether it has memory or an on-board power source whereas Generation refers to a tag specification's major release or version number.

2.6. Communications techniques of Tag Architecture

The communication flow in the RFID system is in either the reader-to-tag or tag-to-reader direction depending on the type of tag. In passive tag, the EPC/information is sent to the reader by reflecting or backscattering [57]. A pictorial representation of transmitted energy between tag and reader is shown in ***Fig.10.*** Unlike passive tag, active tags has ‘on-board’ power source. This power is used to deliver energy for transmitting the data from the tag. This energy is also a source for other electronics components of the tags present in the tag ***Fig.11.***

The semi-active tag also has ‘on-board’ battery but this battery is used for driving the auxiliary electronics (sensors, user-interface etc.) circuit only. The data to the reader is sent using backscattering technique. The semipassive tags, reader always initiates the communications as shown in ***Fig.12***.

Table 7: EPC Class Structure.



EPC Class	Definition	Programming
Class-0 Gen-1	Read Only, Passive tags	Programmed by the factory
Class-1 Gen-1	Write-Once, Read-Many, Passive tags	Programmed once by the user then locked
Class-1 Gen-2	Write-Many, Read-Many, passive tags.	Programmed once by the user then locked
Class-2	Rewritable passive tags with extra functionally like encryption, emulation [3]	Re-programming
Class-3	Semi-passive tags that supports broadband communications	
Class-4	Active tags that can communicate to other peers.	
Class-5	Readers, they can power other tag of class (I, II, III) and as well can communicate to class IV wirelessly.	Not applicable

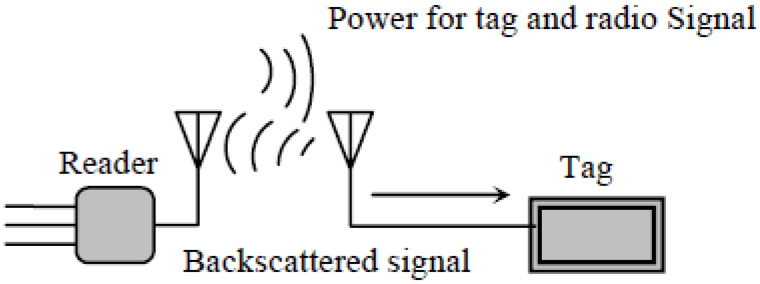


Figure 10: Communication between reader and passive tag [57].

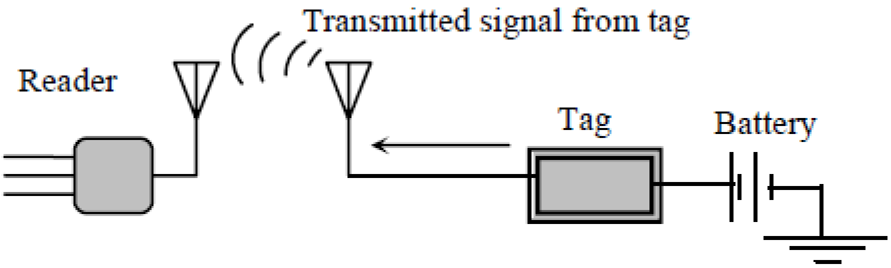


Figure 11: Communication between reader and active tag [57].

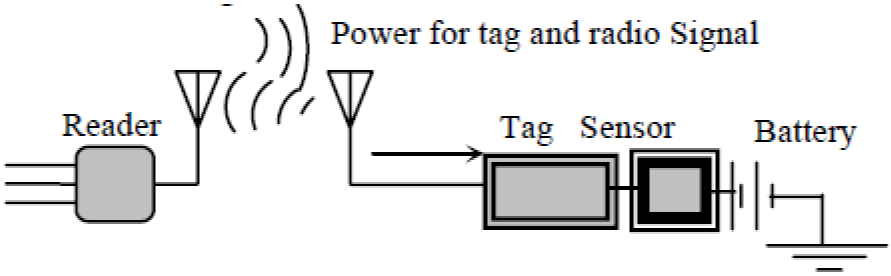


Figure 12: Communication between reader and semi-passive tag [57].

2.7. Overview of RFID Readers

A typical RFID reader or interrogator is a specialized radio whose antenna collects the signals sent by active and semi-active tags or reflected (backscattered) signals from passive and semi-passive tags. In other words, the reader acts as a bridge between the application software and the tags that transfer the information. RFID readers can have multiple antennas to achieve greater operating range or area of coverage. Readers can be placed in a fixed position such as in portal applications, or be portable hand-held for many scanning applications. ***Fig.13***, shows an example of a commercially available RFID reader. In active and semi-active RFID systems, the reader is a specialized receiver that detects the received signals actively being sent by tag transmitters. However, in passive RFID systems, the reader not only listens for the signals reflected from the tags, it also transmits the RF signal that powers up the tags. The semi-active and semipassive RFID readers send a signal to activate the battery in the tags, and detect the actively transmitted signal from the semi-active tags and the backscattered signals from the semi-passive tags. Passive RFID readers power up their tags with two major EM coupling methods [51]:

- Magnetic Field Coupling
- Electric Field Coupling

Each of these coupling methods has an influence over the communications range of RFID systems and is described in more detail in the next subsections.

Figure 13: Example of an RFID reader [51].

2.7.1 Magnetic Coupling: Near Field

In nearfield or magnetic coupling the tag antenna is inductively coupled with the strong electromagnetic (EM) field around the reader's antenna coil. This is the same principle used in transformers where from Faraday's law the reader's alternating magnetic field (primary coil) generates a voltage in the tag's antenna (secondary coil) . Nearfield coupling occurs mostly in LF and HF RFID systems where the distance between the tag and the reader antenna is much smaller than their wavelength (i.e. 13.56 MHz has a 22.1 m wavelength). Therefore, this type of coupling provides very limited read ranges for RFID systems. ***Fig.14***, illustrates the concept of tag powering using magnetic coupling [58].

The magnetically coupled tags have an antenna with a multi-turn coil where each coil is an LC circuit tuned to the desired frequency (i.e. 13.56 MHz) to maximize the energy collection from the readers by alternating magnetic field. The number of turns in HF tag antenna coils is less than the number of turns in antennas for LF tags. In this type of coupling, tag-reader communications is based on modulating the digital data by alternating the strength of the magnetic field that in practice provides *AM modulation* for the digital data to be transmitted. Magnetically coupled tags have very limited energy storage capacity, hence the magnetic field has to be applied constantly during tag interrogation.

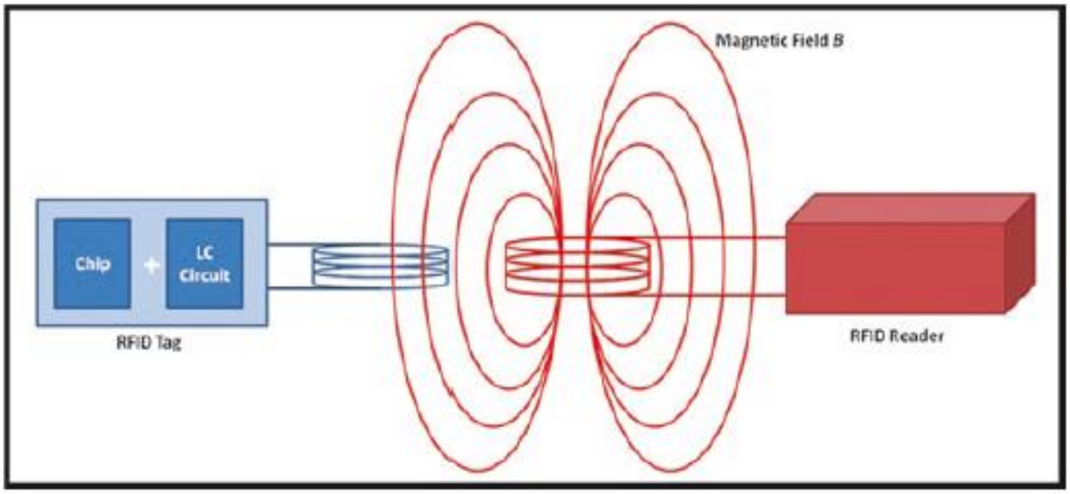


Figure 14: Magnetic (nearfield) coupling to power up a transponder [51].

2.7.2 Electric Coupling: Far Field

Electric or capacitive coupling is used in higher frequency (UHF and microwave) tags and provides a much longer communications range for RFID systems compared to magnetic coupling technique. The energy transfer in this coupling method is achieved in farfield, where the electric and magnetic field components of an antenna propagate into free space as a combined electromagnetic wave. It's important to note that in the far field, inductive coupling is no longer possible since the magnetic field is not linked to the antenna any longer [58].

Electric field coupling uses the same principle as radar where the transponder is powered up by the strong electrical field generated by its reader and reflects (backscatters) the received signal. ***Fig.15,*** represents the electric coupling of a tag by its compatible reader. In electric coupling, tag-reader communications occurs by variations in the load impedance of the tag antenna resulting in a unique backs-

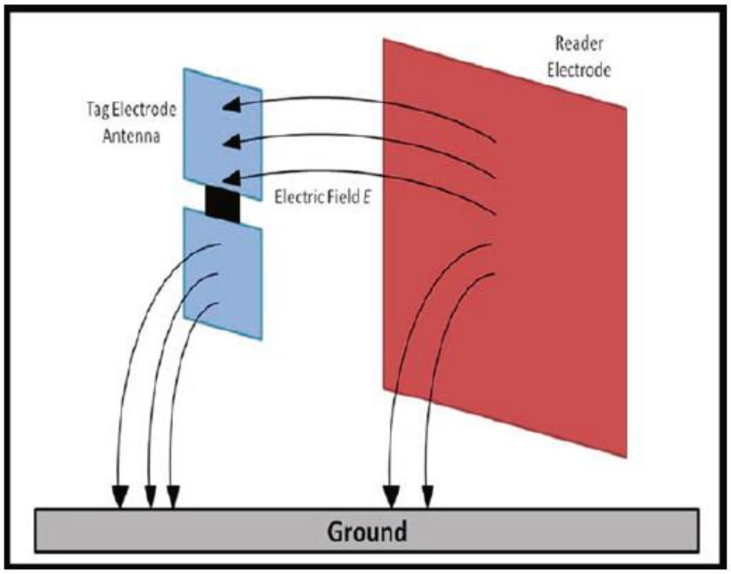


Figure 15: Electrically coupled RFID systems [58].

cattered signal that can be decoded by the reader. In this modulation technique, the tag is intentionally mistuned to its antenna's frequency to reflect the received signal instead of absorbing it.

2.7.3. Electromagnetic Backscatter System

The electromagnetic backscatter system operates at ultra-high frequencies and at the microwave frequencies. The short wavelengths of these frequencies facilitate the construction of antennas with far smaller dimensions and greater efficiency than would be possible using frequency ranges below 30 MHz. The reader sends out a certain amount of energy i.e., electromagnetic waves, which is received by the antenna of the tag. When the antenna of the tag is in the readers' generated field it perceives like an echo that changes back and forward from a strong signal to a weaker and by changing the antennas properties via short-circuits, the reader believes that the size of the antenna changes from $1/4$ of the wavelength to $1/8$ of the wavelength. The communication is based upon electromagnetic waves that the reader sends out. The tag gets its power from the electromagnetic wave. This enables the tag to send its information to the reader [59].

The distinction between the RFID systems with far fields to the near fields is that the near fields use LF (lower frequency) and HF (higher frequency) bands. While RFID systems with far fields usually use longer read range UHF and microwave [60].

2.7.4. Two-way system

The two-way system uses two-way tags with a transmitter and is operating optimally on the microwave frequencies. The tag or transponder, which contains an electronic circuit is attached to the object that requires a unique identification code. When the tag comes near the reader, the radio frequency (RF) field generated by the reader will power up the tag and cause it to continuously transmit its data by 'pulsing' the radio frequency. The data is then captured by the reader and processed in the back-end by applications like the Enterprise Resource Planning (ERP) or Supply Chain Management systems. Data may be read only or programmed by the reader. One reason for using the microwave frequency is when inductive coupling cannot provide the power to the tag. The microwave systems have the advantage of longer reading ranges. A devastating problem is known as “Standing Wave Nulls”. This means dead areas within the reading field in which the tag can’t be accessed. When the signal bounces between metal at a distance equal to a multiple of its half wavelength, it forms a standing wave pattern with some points where there is an insufficient signal to operate the tag. This is the same phenomenon that causes “cold spots” in food cooked in microwave ovens [59].

2.8. Problems Encountered in Operating RFID System

Several potential issues must be solved successfully at the front end of the design process. Careful selection of a dynamic solution is important. In every case, a system design approach is required before implementing an RFID solution. The requirements for multiple tags, speed of operation, accuracy, cost and security must all be considered to provide the result demanded by the application. Some of the common problems with generic RFID are:

1) Reader collision: One problem encountered with RFID systems mainly longer range UHF systems is that the signal from one reader can interfere with the signal from another where coverage overlaps. This is called reader collision. This can be avoided by using a technique named Time Division Multiple Access (TDMA) which is a special anti-collision scheme.

The readers are instructed to read at altered times, rather than both trying to read at the same time. By using this technique, RFID-reader does not interfere with each other. But by saying this, two readers that overlap each other in an area will read any RFID tag twice. Therefore the system has to be set up in such way that if one reader reads a tag, another reader does not read it again. There are a lot of companies that point out how important it is that the reader collision software prevents the colliding readers from communicating with RFID tags in their respective reading zones. The Anti-Collision protocol allows the reading of large number of tagged objects at the same time and it ensures that each tag is read only once. The standard method in use is adapted by Auto-ID and it works like this; the reader asks tags to respond only if their first number of the identifier matches the number communicated by the reader. If more than one-tag responds, the reader asks for the next number in the identifier. It remains doing so until only one-tag responds. This phenomenon happens very quickly and RFID-reader can read 50 tags in less than a second. Different vendors have developed different systems for having the tag respond to the reader one at a time. Since they can be read in milliseconds, it appears that all the tags are being read simultaneously.

2)Interference: Like other technologies using radio waves (garage door openers, remote control toys, pagers, etc.), RFID systems are subject to interference from unwanted signals electromagnetic noise. To protect against "misreads", tag data contains bits that are encoded to provide error detection by the reader to improve the reliability of the system.

3) Presence of metal: The presence of metal can block the performance of RFID readers and tags as well, which affects read range. However, metal can also enhance or amplify the read range of RFID with good system design.

4) Presence of water*:* The presence of water can also impede the performance of RFID, but as with electricity and water, good system design can overcome most limitations [61].

2.9. Performance Limitations around Metallic Surfaces

One of the major challenges that RFID systems with narrowband signaling face is the poor performance around EM reflective objects and materials. This is due to multipath phenomenon caused by reflection of continuous RF waveforms from metallic surfaces that can destructively add and degrade the received signal. ***Fig.16,*** represents multipath phenomenon in narrowband signaling [62]. Although multipath effects can also degrade the performance of active tags, their effect on passive tags can be more dramatic. Since passive RFID tags have to extract power from their reader's transmitted signal, if the energy transfer is not efficient due to antenna impedance mismatch near conductors, such as a metal surface, the tag will not power up and will fail to operate. Because antenna efficiency is a function of frequency, the lack of frequency diversity can result in significant performance degradation of tags that are attached to metal surfaces.

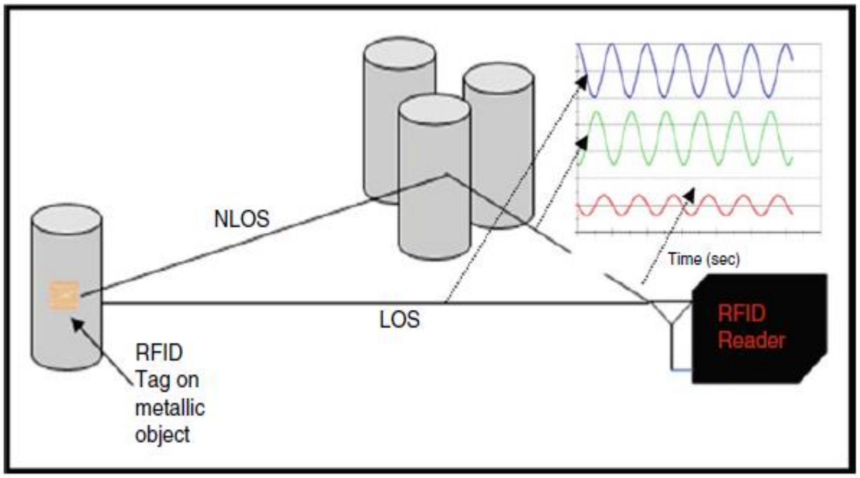


Figure 16: Representation of multipath phenomenon in a wireless link on narrowband signals [60]

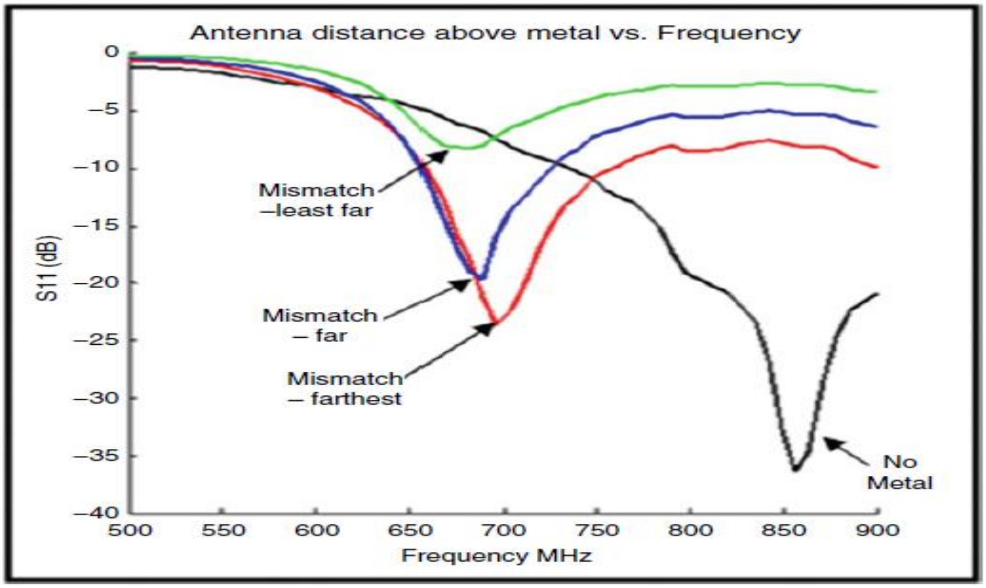


Figure 17: Simulated response of a typical UHF tag over a metallic surface at various distances and as a function of frequency. There is a large impedance mismatch as the tag gets closer to the metallic object [58].

Fig.17, shows the simulation results of reflection coefficient (S_{11}) versus frequency for a typical UHF passive tag at various distances from a metallic object. As shown in the above simulation, the passive tag's antenna becomes de-tuned in the presence of a metallic object. The shift in resonance frequency from the tag's operating frequency (for example, 850 MHz) and hence the impedance mismatch between the tag and reader frequencies causes the tag to receive less energy from its reader. This will cause severe deterioration of the read range and therefore undermines the performance of the passive tag. ***Fig.18***, shows the simulated radiation pattern of a UHF tag antenna in free space and on a metallic object. As shown in ***Fig.18,*** the performance response (radiation efficiency) of a UHF tag antenna severely degrades when it is located in the close vicinity of a metallic surface [63]. Benchmarking of UHF passive tags in the presence of conductive materials is presented in *Sect. 2.10*. In theory HF passive tags (operating at 13.56 MHz) generally performs better, compared to UHF tags, around metallic surfaces due to their lower frequency and better penetration properties. However, these tags have shown serious limitations in read range when they are in contact or in close vicinity of a metallic surface. ***Fig.19,*** represents the read range performance of a commercial passive HF tag versus its distance from a metallic object. As shown in

Fig.19, the read range of the HF passive RFID tag is noticeably reduced as the tag gets closer to the metallic object to a point that there is no read capability when the tag is placed directly on the metal. Since HF tags use inductive coupling to communicate with their reader, the "tag-on-metal" challenge for such tags can be explained by the Eddy current induced from metallic surface that is hit by the magnetic field generated between the tag and its reader. This induced Eddy current generates a magnetic field that is in opposite orientation of the original magnetic field between the tag and its reader (Lenz's law) [63]. ***Fig.20,*** illustrates the change in magnetic lines due to Eddy currents when tag is placed on a metallic object.

The interference between the two magnetic fields results in magnetic deflection; causing poor performance of HF tags around metallic surfaces since the tag's coil will not receive enough magnetic flux to power up. The fact that RFID tags perform poorly in the presence of metallic objects can be used in shielding/coupling attacks by adversaries [64]. In shielding attacks the tag-reader communications is disrupted by wrapping the tagged item in a piece of aluminum foil, where in coupling attacks the tagged item is placed near a ferrous material that can detune the tag frequency to stop the communications with its reader.

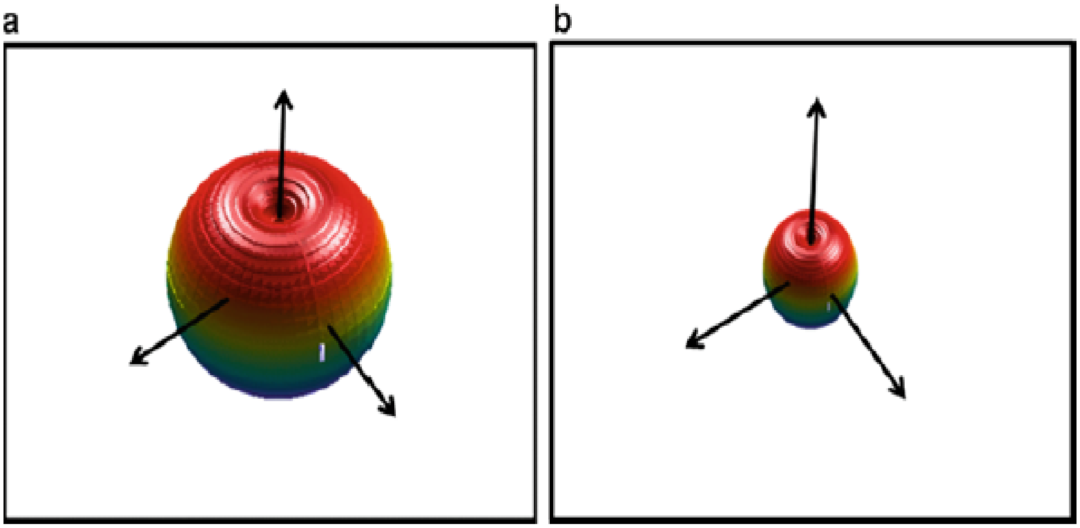


Figure 18: Simulated radiation pattern of a UHF tag antenna in (a) free space and (b) on a metallic object

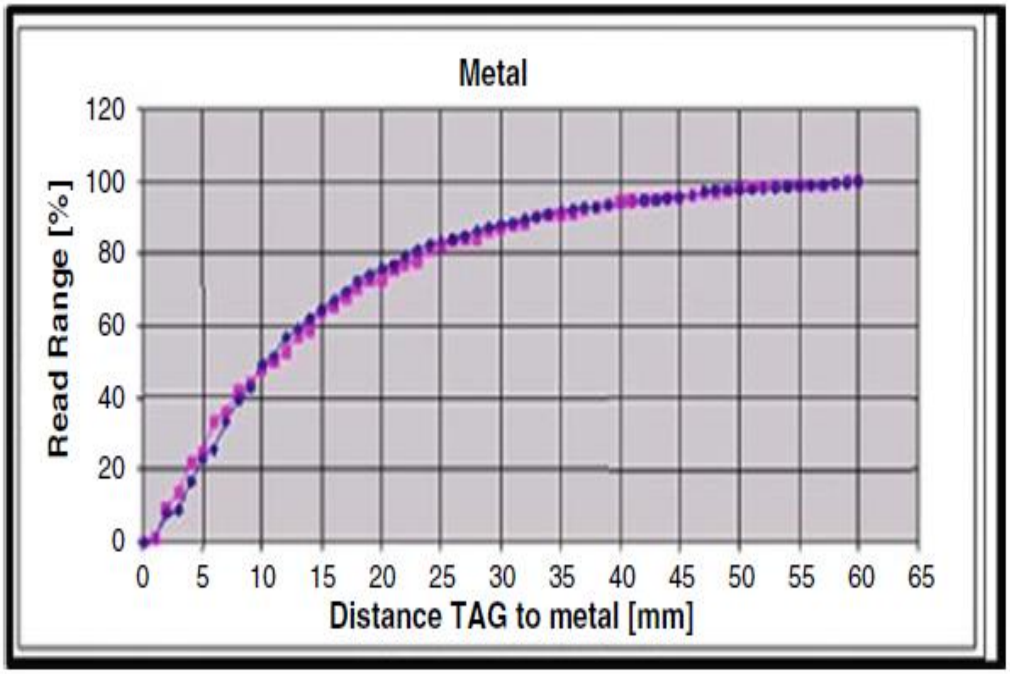


Figure 19: Effect of metallic objects on tag-it transponders [58].

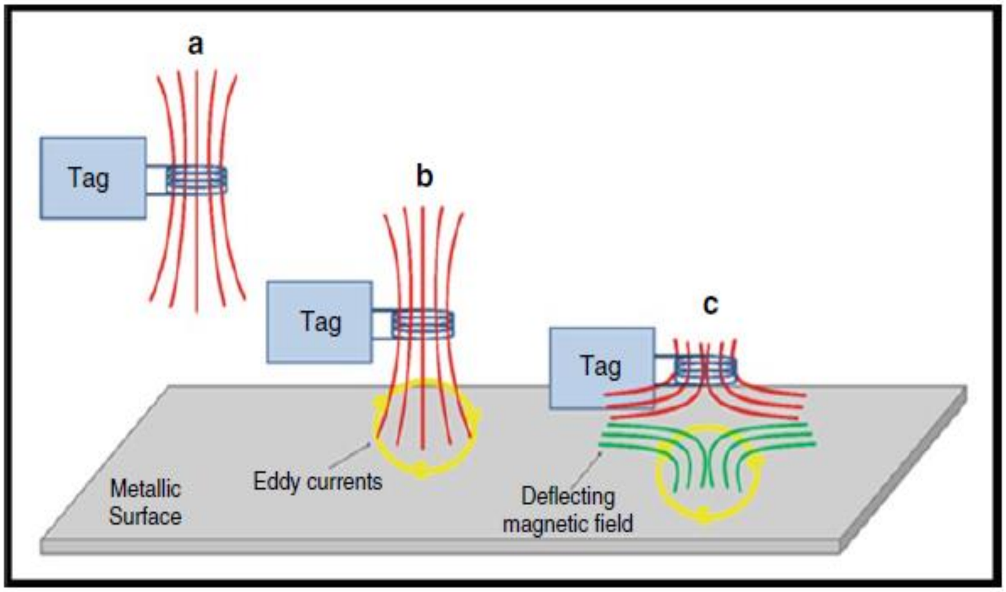


Figure 20: Illustration of the change in magnetic lines as the tag gets closer to a metallic Surface, (a) tag in air, (b) tag near metal (c) tag on metal [58].

2.10. Reading range

An RFID system's reading range is defined as the maximum distance that could be used to have a successful communication between the reader and the tag. The range can vary from a few millimeters to tens of meters. The maximum range between a tag and a reader can vary depending on three main areas [65] [66]:

- Frequency
- Signals
- Readers and antennas

The reading range increases when the frequency increases. The signal strength from the antenna differs depending on whether it is an active or passive tag in use. The reading range is longer when using an active tag. How the antenna of the reader is directed in relation to the tag is important. The size of the antenna and the power of the reader are also significant. ***Table.8,*** shows the different reading ranges.

Table 8: Different reading ranges.

Frequency range	**Technology**	**Reading range(m)**
Low 125-134 kHz	Very short range	0 – 0.4
High 13.56 MHz	Short range	0.9 – 3.5
Ultra High 860-960 MHz	Medium range	0 – 10
Microwave2.4-2.5(5.8) GHz	Active Beacon(long range)	50 – 100
Microwave2.4-2.5(5.8) GHz	Two-Way Active(long range)	50 – 100
Microwave2.4-2.5(5.8) GHz	Real-Time Location System(long range)	50 – 100

2.11. Range for Passive Tags

Since passive tags do not have an internal source of power and collect energy from their reader signaling, their communications range is very limited. In the passive tag category, the UHF and microwave tags have longer read ranges than the LF and HF tags. This is due to the fact that the operation of microwave and UHF tags is based on the far field communications, because the distance between the tag and reader antenna is typically longer than one wavelength in such frequencies (33 cm for UHF, and 12 cm for microwave tags), ***Fig.21***. In far field communications, the power in the transmitted signal decays in proportion to the square of distance from the antenna, where in near field communications (LF and HF tags) the signal power decays as the cube of the distance from antenna as shown in (16) and (17) respectively [67].

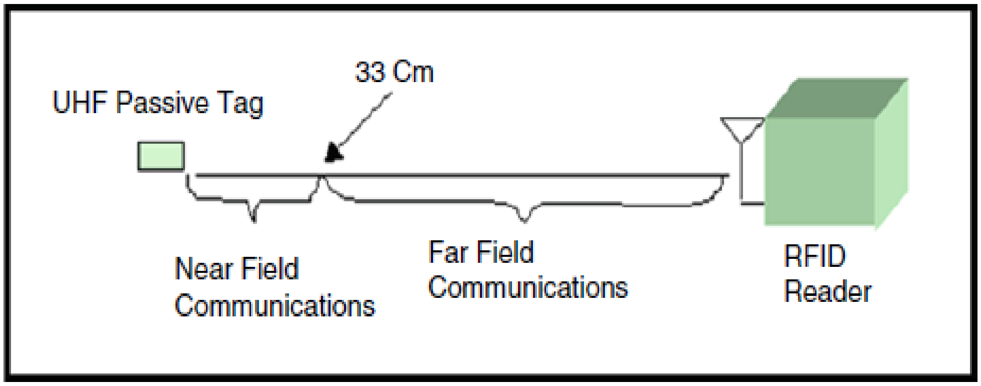


Figure.21: Illustration of near field, and far field propagation modes for UHF passive tags. The near field-far field boundary (33cm) is defined by one wavelength of the tag's operating frequency [58]

Table 9: Forward link (reader-to-tag) budget analysis of a typical passive, UHF tag at 915 MHz operating frequency.

Reader transmit power	30 dBm
Aperture and path loss (3 m)	−41 dB
Reader transmit antenna gain	6 dBi
Tag antenna gain	2 dBi
Received power at tag	−3 dBm
Required power to activate the tag	−10 dBm
Link margin	+7 dB

$$P_{tag} \propto {}^{1}\!/_{d^2} \qquad (2.1)$$

$$P_{tag} \propto {}^{1}\!/_{d^3} \qquad (2.2)$$

Where *tag P* depicts the power received at the tag from its reader, and d is the distance between the tag and its reader. Although UHF tags have longer communication range compared to lower frequency passive tags, their read range is still not acceptable for many applications. Link budget analysis of the forward link (reader-to-tag) for a typical UHF tag in ***Table.9***, shows that under regulatory restrictions at a 3 m distance, the forward link margin is marginal (about 7 dB). This theoretical margin is based on the assumption that tag-reader communications occur in free space. In many practical scenarios, the 7 dB margin can easily be reduced to an even lower number, often by many factors, in real environments. The environmental factors affecting the tag performance include the presence of interferers, conductive and absorptive materials such as metal and liquids respectively, diffraction, and shadowing effects. The decrease in forward link margin demands even shorter distances between UHF passive tags and readers for reliable communications.

The calculations in ***Table.9,*** are based on the following operating parameters:

- Reader transmits power at 1 W (maximum FCC limit)
- Free space path loss at 3 m per (2.3)

$$P_r = P_{tx} \, {}^{A_e}\!/_{4\pi d^2} \qquad (2.3)$$

Where P_r is the received power at the tag, P_{tx} is the transmitted power from the reader, A_e is the effective aperture equal to ${}^{\lambda^2}\!/_{4\pi}$, and d is the distance between the tag and its reader.

- Reader antenna is assumed to be isotropic with 6 dBi gain.
- Tag antenna is assumed to be isotropic with 2 dBi gain.
- Power required by the tag is 100m Watt limited by silicon process. Typically, CMOS process can reduce the power requirement of the tag.

Although forward link (reader-to-tag) in UHF passive tags is limited to short ranges (< 3m), the reverse link (tag-to-reader) is only limited to the reader sensitivity.

Table 10: Reverse link (tag-to-reader) budget analysis of a typical passive UHF tag at 915 MHz operating frequency

Tag incident power	−3 dBm
Aperture and path loss (3 m)	−41 dB
Tag antenna gain	2 dBi
Reader receive antenna gain	6 dBi
Tag modulation loss	−6 dB
Received power at reader	−42 dBm
Reader sensitivity	−100 dBm
Link margin	+58 dB

Sensitive readers can pick up signals as low as −90 to −110 dBm, so the reverse link margin could be very large as shown in Table 2.10.

The numbers in ***Table.10***, is based on the following operating parameters:

- Tag incident power of −3 dBm (from Table 2.9)
- Symmetric path loss for forward and reverse links
- Tag modulation loss of −6 dB defined by (2.4):

$$K = \alpha|\rho_1 - \rho_2|^2 \qquad (2.4)$$

Where K represents the tag modulation loss, α modulation coefficient, $\rho_1 and\ \rho_2$ are tag reflection coefficients.

As shown in ***Table.10***, the reverse link has a very large margin (58 dB), hence the UHF reader is capable of reading a passive tag from much longer distance compared to the distance it can power up the tag. So the limitation in range for UHF passive tags is really related to their forward link. If UHF tags can be powered up more efficiently, sensitive readers can pick up tag’s backscattered signals from very far distances (Km range, with a reader sensitivity of −100 dBm). This can cause vulnerability in detecting tags by unauthorized readers from long distances.

2.12. Data Transfer between a Tag and a Reader

2.12.1 Signal Transmission

For an RFID system to work, we need three processes: energy transfer, downlink, and uplink. According to this we can divide RFID systems into three groups: full duplex, half-duplex, and sequential. During full duplex and half-duplex operation, the energy is transferred constantly, compared to sequential operation when energy is first transferred by the reader and then the tag responds. In half-duplex systems the information is sent in turns either transferred inductively through load modulation or as electromagnetic backscatter, such as with radar [68].

In full-duplex systems uplink information is sent on a separate frequency, either a subharmonic or not, so the flow of information can be bidirectional and continuous. Sequential transfer consists of two phases: First energy is sent to the tag that stores it in a capacitor, then, utilizing the power received, it can function for some time and send its reply. This has the advantage that by extending the charging time and enlarging the capacitor it is possible to acquire more energy for the electronics.

2.12.2 Data Transfer Rate

A further influence of carrier frequency is with respect to data transfer, for which it is very important to understand the bit rate (data rate) concept. Whereas in 182 RFID Design Principles theory it is possible to transfer binary data at twice the carrier frequency, in practice it is usual to use many cycles of the carrier to represent a binary digit or group of digits. However, in general terms, the higher the carrier frequency, the higher the data transfer rate that can be achieved. So, a low-frequency system operating at 125 kHz may transfer data at a rate of between 200 and 4,000 bps depending on the type of system, while rates up to greater than 100 Kbps (but typically less than 1 Mbps) are possible for microwave systems. It should also be appreciated that a finite bandwidth is required in practice to transfer data, this being a consequence of the modulation that is used. Consequential to transfer capability is the data capacity of the tag. Loosely speaking, the lower the frequency, the lower the data capacity of the tags, simply because of the amount of data required to be transferred in a defined time period. Keep in mind that the capacity can also be determined by the manner in which the tag is designed to be read or written to (for read/write tags), be it in total or part. The choice of data transfer rate has to be considered in relation to system transfer requirements— this is determined by the maximum number of tags that may be expected to be read in a unit interval of time multiplied by the amount of data that is required to be read from each tag. Where a write function is also involved, the number of tags and write requirements must also be considered [51].

2.13. Performance near Metal and Water

The presence of a material near tags changes the characteristics of the tags antenna. The materials that are common and pose greater challenges to tag performance are metal and water. Water and metal affect tag performance in a number of ways, they provide multi-path and create fading zones. In fact, metals can be used to boost the performance of tags. The presence of high-dielectric material in the near field of the tag causes detuning of the antenna, so the antenna would resonate at a lower frequency. The presence of material changes the impedance bandwidth of the antenna and reduces the power transfer efficiency, thus, the presence of materials near tags affects the frequency response of the tags. In this way, the higher the number of frequencies under consideration, higher would be the resolution of the frequency response.

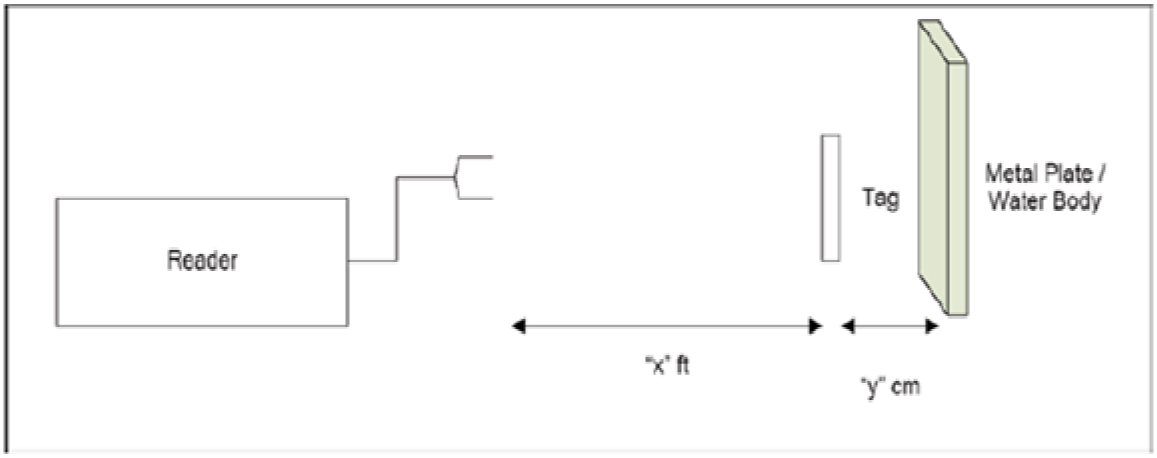


Figure 22: Tag near Metal / Water **[51].**

3o ΚΕΦΑΛΑΙΟ

CHAPTER THREE

III

This chapter explains about the ranging technology of *WSNs*, which is the heart of any localization system, its error characteristics and failure modes often determine the design and applicability of the rest of the system. First we display the radio propagation of *WSNs* and the classification based on signal metrics, then we also explains the characteristics of received signal strength, indoor area measurements. Last obstacles Indoor Area Measurements are presented. Indoor Signal Propagation Characteristics

3.1. The Ranging Technology

Radio wave propagation is defined as the transfer of energy by electromagnetic radiation at radio frequencies. Radio propagation studies look at how radio waves travel through a given medium such as air. Radio waves encounter various outdoor objects ranging from buildings and plants, and indoor objects, such as walls and furniture. These objects obstruct radio wave propagation and affect the amount of time it takes for the wave to reach the receiver from the transmitter. In addition to the interference caused by obstructions, other factors, such as terrain, wave frequency, and velocity of the transmitter and receiver, all impact radio propagation. Since 802.11 works over the 2.4-GHz frequency, there is interference from microwaves, Bluetooth devices, cordless phones, and other similar devices. Multipath fading, where a signal reaches the receiver through different paths, each having its own phase and amplitude, is another common problem faced by radio waves. Even environmental changes such as humidity and temperature affect the signal strength. At a fixed location, the signal strength received from an access point varies with time and its physical surroundings.

The wavelength of the radio waves used by a wireless local-area network (*WLAN*) is significantly smaller than the obstructions that the radio waves encounter, therefore, it can simplify the study of these waves by treating them as rays traveling in straight lines. The shortest path that a wave can take is the unobstructed path, or the *LoS*. When obstructions are encountered, the signal has to take multiple paths to travel from the transmitter to the receiver. This behavior, called multipath delay spread (more on multipath below), introduces a delay in the transmission time when compared to *LoS*. Usually, *NLoS* transmitter radio channels have characteristic random multiple-path radio propagation, with the principal parameters of multipath fading, shadowing, and path loss. Traditionally, the transmission link of such a system is modeled by an elevated base station/receiver antenna, a relatively short *LoS* propagation path followed by many long *NLOS* reflected propagation paths and an antenna on a mobile transceiver. Variations in the channel occur due to changes in the static environment, moving interferers, and motion of the user/transceiver. When natural and constructed obstacles, and especially movement in the environment or a transmitter, result in multiple signal paths, the situation is referred to as multipath propagation, influenced by the above factors [67].

Particularly relevant to location sensing are the radio propagation behaviors that cause the signal transmission to take a longer path or be delayed. One approach involves measuring the time it takes for a signal to reach its destination and based on that measurement, calculating the distance traveled. Any radio propagation delay scan ultimately introduces errors into the distance calculations. Signal attenuation is perhaps the most fundamental technical problem to be addressed, because no radio positioning system can operate when the tracking signals are too weak to be received. Any receiver is essentially a device that separates signals from noise and recovers the information content of those signals. Usually, there are only one or a few sources of the desired signal, but there are many sources of noise in a typical environment. In general, given typical wood or reinforced concrete buildings, attenuation is an increasing function of frequency. This explains why *GPS* does not work indoors. Its microwave carrier signal at 1.5 GHz undergoes severe attenuation in the course of passing through even the thinnest roofing materials. Commercially available indoor radio positioning systems use the ISM allocation at 2.4 to 2.45 GHz. These frequencies are attenuated even more severely by passage through materials as common as reinforced concrete, people, and plant leaves. It is not uncommon for a 2.4-GHz signal to be attenuated by more than 20 dB when a single reinforced concrete wall appears in an otherwise free-space signal path. In general, sources of error for signal propagation arise from the receiver's equipment, noise and interference, propagation channel (multipath and *NLoS*), which is a range/direction estimation error which is a range/direction estimation error most important impact on location accuracy), and nonlinear algorithm (positioning error).In most cases, signal propagation in indoor environments is usually affected by multipath. In wireless networks, the straightest path or *DLoS* between objects is often difficult to ascertain.

Wireless signals are also attenuated with increasing distance and obstacles in their paths. If the signal strength is below some threshold value, the receiving antenna will encounter bit errors when decoding the signal, which gets worse under significant RF interference from other sources. Encountering such bit errors, the receiver does not send an acknowledge signal back to the sender, causing the sender to retransmit the frame. These retransmissions decrease the data rate of the system. So as the distance between the receiver and the transmitter increases, the data rate of the system decreases. Thus, in order to increase the data rate, the coverage area should be decreased [69].

If the signal strength falls below the receiver sensitivity, the transmitter is disconnected from the particular receiver. The receiver sensitivity depends on the wireless technology used and the data rate of communication. The receiver sensitivity is lower for higher data rates, and also determines acceptable path-loss measures. Also, dead spots are present where there is no received signal due to these effects.

Therefore, before deploying a *WLAN*, an *RF* site survey should be performed for producing signal propagation models, enabling the determination of optimal locations of transceiver to provide the best possible coverage.

3.2. Classification Based on Signal Metrics

The basic function of a wireless positioning system is to gather particular information about the position of an object and process that position into a location estimate. The particular information could be one of the classical geolocation metrics for estimating the position, ***Fig.23***.

- Angle of arrival (*AOA*)
- Time of arrival (*TOA*)/time difference of arrival (*TDOA*)
- Received signal strength (*RSS*)

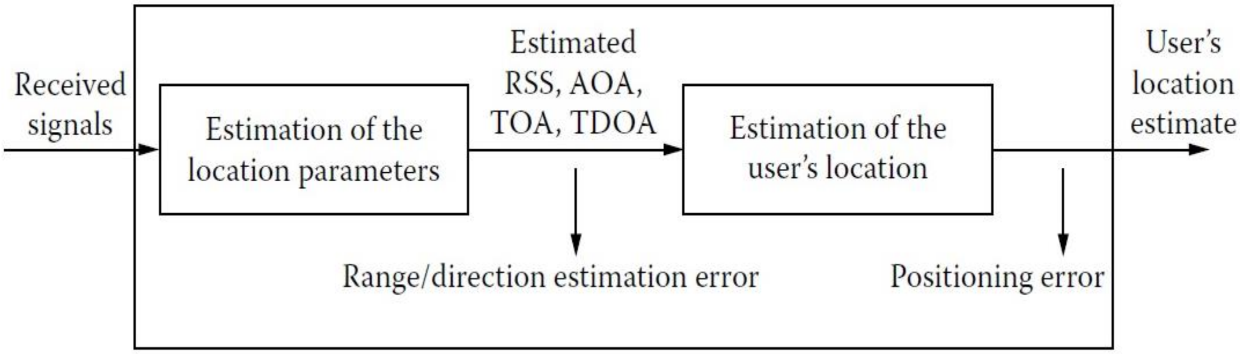


Figure 23: Position estimation based on several variants techniques metrics **[69].**

3.2.1. AOA Positioning Technique

This technique computes the angle of arrival of the signals from the transmitter to more than one base station, making use of directional antennas and using simple geometric rules to calculate the distance from the angle measurements. Two beacons are enough to accurately estimate the object's location. Each estimated angle gives a line between the receiver and the transmitter. The lines of position are straight lines whose intersection provides the location of the transmitter. The accuracy of *AOA* diminishes within creasing distance between transmitter and base station due to the scattering environment, ***Fig.24,*** shows that the received signals at two base stations (array antennas) and the estimation algorithm provide angle or direction estimates between the object and base stations, and ***Fig.25,*** shows *AOA* methods may use at least two known reference points *(A,B),*and two measured angles $\theta 1$, $\theta 2$ to derive the 2-D location of the target *P* [70].

Disadvantages include the following:

- Need of extra hardware, antenna arrays at the receiver. The performance of this system highly depends on the accuracy of the antennas used for the angle measurement.
- Need for *LoS* conditions for accuracy.

- Changing scattering characteristics and multipath signals hinder the performance.

One way of reducing the scattering characteristic and the multipath issues is to elevate the antenna to an appropriate height (which makes these systems almost impractical for micro-cell-based networks).

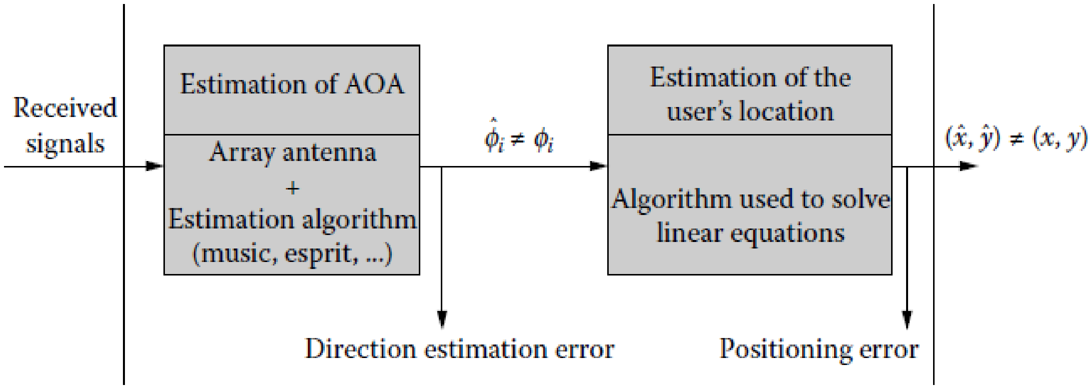


Figure 24: Received signal angle estimates **[69].**

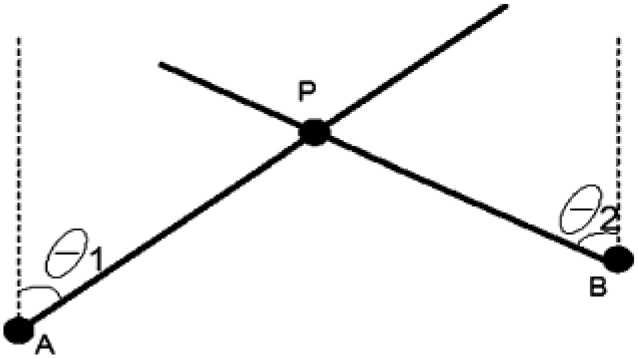


Figure 25: Position based on AOA measurement **[70]..**

3.2.2. *TOA/TDOA Positioning Technique*

The distance between the transmitter and receiver can be calculated using *TOA/TDOA* information as well. The *TOA* technique is based on estimating the time of arrival of a signal transmitted by the transmitter and received at the minimum of three base stations. The *TDOA* technique is based on the time difference of arrival of a signal received at multiple pairs of base stations. Knowing the distances (having obtained the *TOA* information, the distance between the transmitter and the receiver is just the speed of light times the travel time) to each receiver, location can be calculated using the triangulation method.

The usage of *TDOA* information is very similar to that of *TOA*, but this time the difference between the distances from the transmitter to each receiver is calculated. The lines of position are hyperbolas (instead of circles as with *AOA*) whose intersection provides the location of mobile station. The use of time of flight of signals to measure distance is not a new concept. *GPS* uses the one-way delay of radio waves from satellites to estimate distance, while collision avoidance mechanisms used in robotics determine the distance to obstacles by measuring the time of flight of an ultrasonic signal being bounced off them. The major concern with this type of technique is the preciseness of time measurement, and unlike other techniques, the error factor decreases as the distance between the mobile station/transmitter and the base station\ receiver increases. Since the time delay to be measured in microcellular technologies is very small, technologies like Bluetooth do not easily support this technique. ***Fig.26***, shows the received signals at three base stations and estimation algorithms provide time/time difference estimates between the transmitter and base stations (pairs of base stations). Finally *TDOA* technology therefore can be applied to a wide range of wireless networks (primarily Time Division Multiple Access (*TDMA)*, Code Division Multiple Access (*CDMA)*, and Frequency Division Multiple Access (*FDMA)* based).

Disadvantages include the network infrastructure needs to be extremely well synchronized (at the MS and the transmitter ends), which in turn implies higher costs.

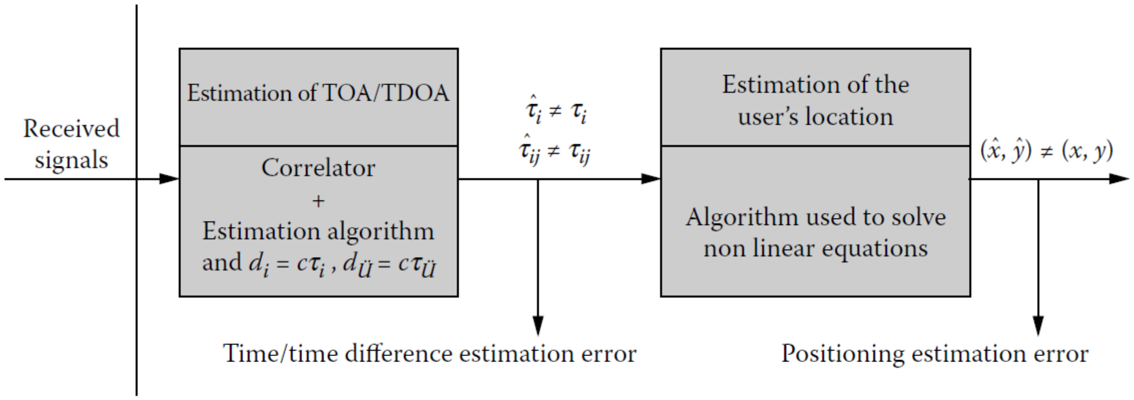


Figure 26: Received signal time estimates **[69].**

3.2.3. RSS Positioning Technique

This approach makes use of the relationship between the received signal strength and the distance. Theoretically, there exists an inverse proportional relationship between the received signal and the distance from the receiving station that can be represented linearly. The distance between the transmitter and the receiver can be determined from the RSS values either at the object device end or at the receiver end. There are two ways to determine the distance. The first is to map the path loss of the received signal to the distance traveled by the signal from the transceiver to the object. Second, with the knowledge of the RSS from at least three receivers, triangulation is used to locate the receiver. Geometrically, if a transmitter is at distance $d_i$from $receiver_i$, possible locations of the mobile are represented with a circle with center at $receiver_i$and radius d_i. There is no database search, and the positioning delay is just related to the communication and computation. However, inside a building, the variation of the RSS with distance (the inaccuracy of the path-loss model) is significant due to obstructions and multipath fading effects.

For indoor environments, it is difficult to find a *LoS* channel between the transmitter and the receiver. Radio propagation in such environments would suffer from multipath effect. The time and angle of an arrival signal would be affected by the multipath effect, thus, the accuracy of estimated location could be decreased. An alternative approach is to estimate the distance of the mobile unit from some set of measuring units, using the attenuation of emitted signal strength. Signal attenuation-based methods attempt to calculate the signal path loss due to propagation [70] [71] [72].Theoretical and empirical models are used to translate the difference between the transmitted signal strength and the received signal strength into a range estimate, Due to severe multipath fading and shadowing present in the indoor environment, path-loss models do not always hold. The parameters employed in these models are site-specific. The accuracy of this method can be improved by utilizing the premeasured RSS contours centered at the receiver [73] or multiple measurements at several base stations. A fuzzy logic algorithm shown in is able to significantly improve the location accuracy using RSS measurement [74].

Signal strength measurements are affected by various radio wave propagation mechanisms [72].There are three ways that signal strength can be affected:

reflection, diffraction, and scattering. Radio waves typically encounter obstructions larger than the wavelength, and depending on the wave frequency and the angle at which they hit the obstruction, the rays are reflected away from the obstruction. Reflection is an important consideration in indoor applications [69]. The radio waves are diffracted when they encounter edges, such as when they come into contact with the edge of a building or a wall. As a result of diffraction, the waves are able to propagate away from the edge and reach places that are not directly within *LoS*. The third mechanism that needs to be considered is called scattering. Irregular objects such as walls, furniture, and leaves on a tree can cause the rays to scatter in all directions. Scattering is observed when the object dimensions are close to the radio wavelength, and becomes a significant issue if the transmitter or receiver is located in a highly cluttered area [72]. ***Fig.27***, shows that received signals at three base stations and a path-loss model provide distance or range estimates (d1, d2, d3) between the mobile device and base station. Each estimated range gives a circle centered at the receiver (base station) on which the transmitter (mobile device) must lie. Range estimation errors are due to multipath, *NLoS*, and local shadowing. Position estimation error is due to the algorithm used to solve nonlinear equations.

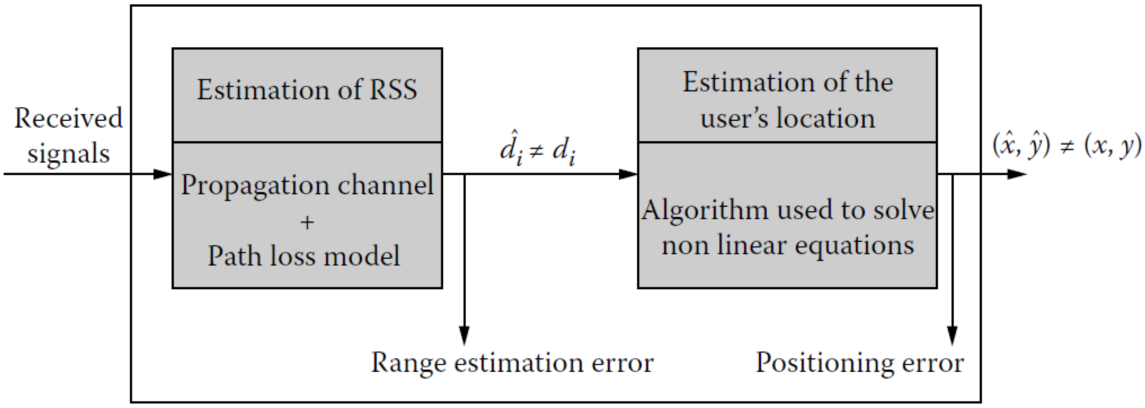


Figure 27: Path loss models measure received signal as a function of distance [69].

3.3. Signal Propagation Characteristics of RSS

Several localization systems have used received radio signal strength to estimate distance between transmitter and receiver. Perhaps the most well-known of these is RADAR [16] which uses existing 802.11 networks. Other commercial systems include PinPoint [75] and WhereNet [76] which deploy specialized RF infrastructure. Recent researches in RFID localization using signal strength include SpotON [45], LANDMARC [38] and MDS [77]. This section analyzes exactly how useful this information might be in localization. It is well known that signal strength information is an unreliable indicator of distance in complex indoor or urban environments due to obstacles and reflections. This is especially problematic because erroneous readings give no indication of being erroneous, causing heavy-tailed error distributions which are difficult to deal with. This does not, however, mean that signal strength is not applicable in sensor networks. Indeed, many sensor network applications are situated in ideal settings for measuring signal strength, e.g. outdoors. Furthermore, in less than ideal environments, signal strength can be used to corroborate measurements from other ranging technologies which might have different failure modes. In radio models, the received signal strength is usually represented with the following formula, measured in decibels [30]:

Received Signal Strength = Sending Power – Path Loss + Fading ***(3.1)***

The *Sending Power* of a node is determined by the battery status and the type of transmitter, amplifier and antenna. *Path Loss* describes the signal's energy loss as it propagates to the receiver. Path loss can be calculated using different physical models. The "Free Space Model" assumes the ideal propagation condition: that there is only one clear *LoS* between the transmitter and receiver with no obstacles nearby to cause reflection or diffraction. The path loss is modeled as being proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. This model accounts for the propagation distance between sender and receiver using a fixed formula for signal loss, and does not include hardware specific factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with mechanical imperfections.

The 'Two-Ray-Ground Reflection Model' considers antenna orientation and distance from ground for both the transmitter and receiver, performing detailed radio ray tracing to estimate reflection of signals. This model is known to give more accurate predictions at a long distance than the free space model. However it does not perform as well at short distance due to the oscillation caused by the constructive and destructive combination of the two rays. In the case where distance between nodes is small, the free space model may be preferred. The effects of reflection, diffraction and scattering of signals as they hit obstacles will influence the free propagation of signals, leading to observation errors at the receiving node, ***Fig.28.*** These effects cause an exponential decay on the signal strength with respect to distance. Signal strength is also assumed to be log-normally distributed for a given distance d. The log-normal shadowing path loss model which is the most commonly used radio propagation model in *WSNs* simulations is given as follows:

$$ {}^{P_r(d)}\!/_{P_r}\,(d0) = -10\,n\log\left(\frac{d}{d0}\right) + Y \tag{3.2} $$

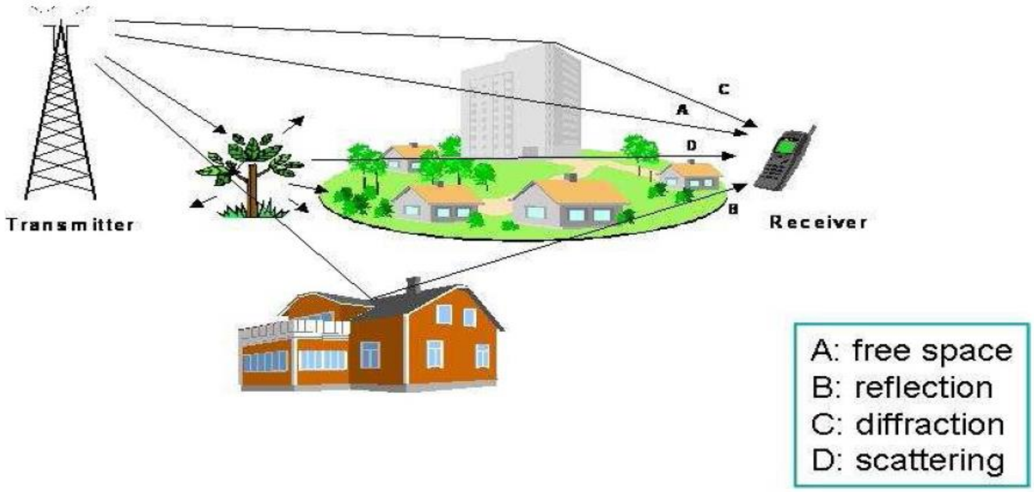


Figure 28: Mechanisms behind the electromagnetic wave propagation.

Where $P_r(d)$ is the received power for distance d and $P_r(d_0)$ is the received power for a reference distance *d0*, n is the path loss exponent (rate at which signal decays). Y is a Gaussian random variable with zero mean and standard deviation σ. n and σ are obtained through curve fitting of empirical data. To approximate a communication link with the shadowing model, Ramadurai [78] suggests a simple approach to calculate the distance using a certain radio propagation model and introduce a random error to the calculated distance.

In other words, received signal strength will decrease by term, $10\,n \log\left(\frac{d}{d0}\right)$. ***Fig.29***, shows the observed mean and standard deviation of signal strength as distance increases, and this curve decreases logarithmically. ***Fig.30,*** plots the ranging error over distance that Signal strength ranging error increases with distance due to the increase in noise and the logarithmic decrease in signal strength. Notice that the accuracy and maximum range can be increased by using a higher transmission power [79].

Two concepts are a key in radio propagation: transmission power and signal strength. Radio propagation is the transfer of energy and is measured in terms of units of power, or watts. This power is measured at the transmitter (transmission power) and also at the receiver; the signal strength is the total amount of power measured at the receiver. Due to the nature of radio wave propagation, the latter measurement is less than the former because the signal loses power as it moves through the air in the form of radio waves.

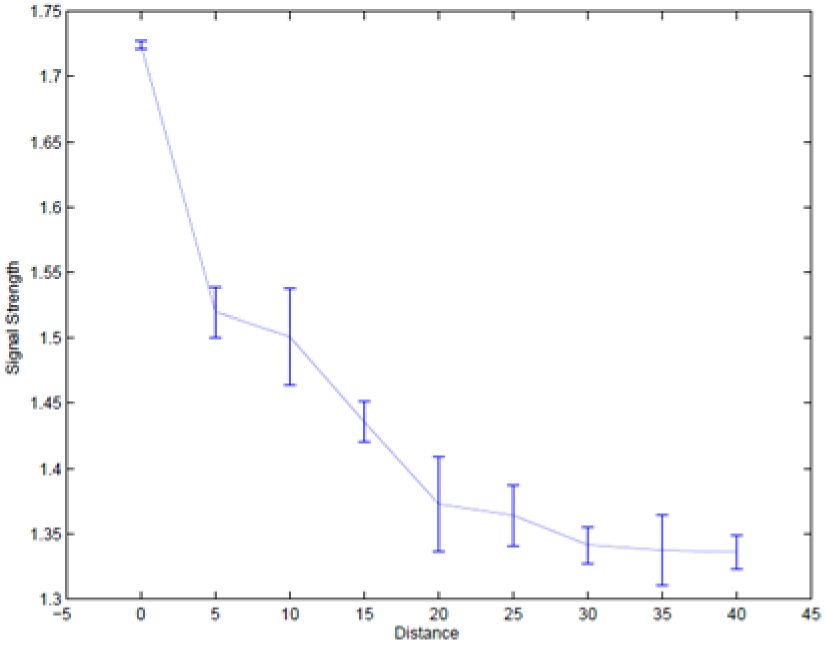


Figure 29: Average Signal Strength Reading vs. distance

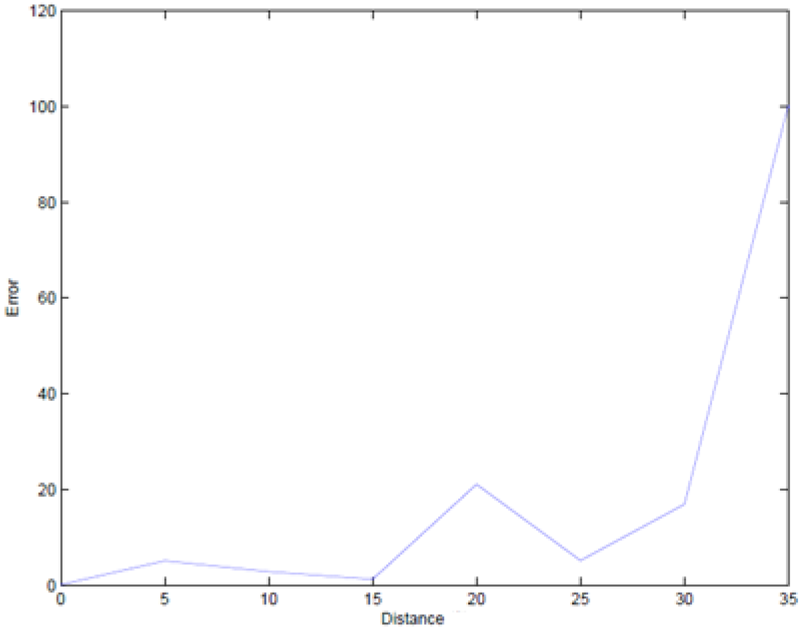


Figure 30: Signal Strength Ranging Error increases with distance

3.4. Indoor Area Measurements

Indoor radio propagation is not influenced by the terrain profile, as is outdoor propagation, but it can be affected by the layout in a building, especially if there are various building materials. The transmitted signal often reaches the receiver through more than one path, due to reflection, refraction, and diffraction of the radio wave by objects such as walls, windows, and doors inside a building, the distanced power model is the main propagation model for path loss. As shown in Eq.3.3, many researchers estimate the rate of decay of a transmitter signal through this relation [80] [81].

Buildings represent a complex environment of very large dimensions compared to wavelength. RSS is location dependent as it is affected by factors such as distance from the transmitter and attenuation due to existing obstacles. As mentioned above, due to reflection, diffraction and scattering of radio waves by structures inside a building, the transmitted signal most often reaches the receiver through more than one path. There are several approaches to indoor propagation prediction. In one approach, electromagnetic theory is applied using ray tracing techniques. In this method, propagation predictions can be applied without performing propagation measurements first. However, computation times on personal computers can be large, and, then, the predictions cannot be obtained interactively or with algorithms for optimizing user locations. In the alternative approach, propagation models related to those for describing free-space propagation are empirically or statistically fitted to the measurement data. The resulting models are generally straight forward to apply, and prediction results can be computed quickly [80]. RSS is a measure of the power received by the RFID tag from a transmitter and provides information as to location of the subject carrying it. The received signal consists of direct, reflected, scattered and diffracted waves. For indoor environments, log-distance path loss model, among different path-loss models, in its simplest form often used for *EM* signals can be expressed as:

$$PL(dB) = PL(d_0) + 10\, n\, log(d|d_0) \qquad (3.3)$$

In (3.3), n is the path loss exponent depending on the building and surrounding medium (is generally higher for wireless channel), which indicates the rate of path loss with the increasing distance. In an enclosed environment, the value of *n*, may be 1.5 to 1.8 when the transmitter and receiver are placed in the same hallway and are in sight of each other. When the receiver is located within a room off the hallway, *n* ranges from three to four. *n* also varies with frequency, and is dependent on the building materials used in a particular environment [82] [83]. ***Fig.31,*** shows the measured RSS levels and the plot obtained by substituting empirically driven parameters in *Eq.3.3,* for a single transmitter [47] .

3.5. Obstacles Indoor Area Measurements

The Indoor Area Measurements may include obstacles, which cause scattering and reflection of radio waves. Obstacles may be walls, desks, metal or wooden shelves, etc. Measured data include recordings of the RFID tag coordinates, and RSS levels.

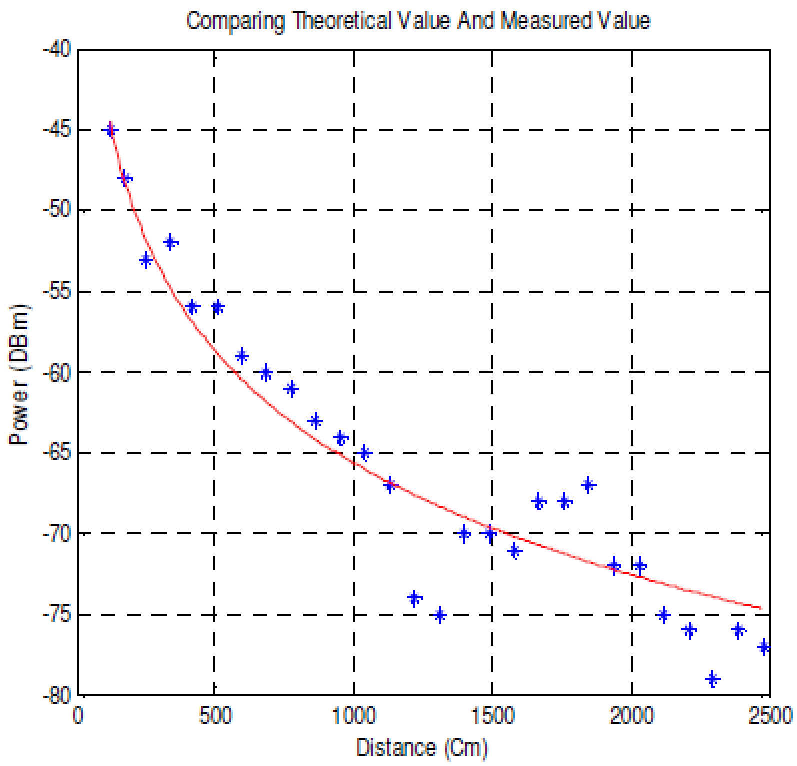


Figure 31: Signal strength values for indoor environment [47].

3.6. Non Line of Site (NLoS) Propagation:

NLoS propagation measurements are dependent on the position of buildings and other geographic features in the propagation environment as well as terminal and base stations positions. In order to calculate bounds on the localization error during *NLoS* propagation, not only must the locations of measuring base stations\receiver and mobile terminal\transmitter be known but also the geometry of obstacles to radio propagation. However, in practice *NLoS* propagation at some locations is deterministic as the *LoS* propagation paths to measuring base stations\receiver are blocked by large immobile objects such as walls or buildings. In other words, *NLoS* radio propagation this path is obstructed and the signal is reflected and diffracted during propagation from the target node to the measuring base stations. *NLoS* propagation complicates the localization problem since the signal characteristics are not only a function of the node and base station locations but also a function of the location of obstructions in the propagation environment, whereas during n *LoS* radio propagation, radio signals travel directly on the shortest straight line path from the node to be located to the measuring base stations [84]. *RFID* modeled has *NLoS* propagation as a random effect with no correlation to a node’s location. In this case, the occurrence of *NLoS* propagation only degrades localization accuracy [85].

3.7. More on Multipath

Multipath is common in radio channels. At the receiver, multipath signals are multiple copies of the transmitted signal, each with a different delay. This results in the correlate or output having multiple correlation peaks of various sizes corresponding to the transmitted code word. A receiver can take advantage of multipath and combine all of the multipath-related correlation peaks out of each code word correlator, and then do the comparison among all such code word correlators. This receiver would perform better than a conventional receiver, which would only look at the correlator output at a particular instant in time. The multipath phenomenon has been recognized in pagers and mobile telephones. In this context, the combination of wireless signals may cancel each other out, making reception difficult. This is sometimes referred to as multipath interference. Efforts have been made to reduce multipath interference in order to improve the signal to- noise ratio or bit error rate of the received signal [69].

Multipath interference is avoided by selecting the strongest received signal for detection and demodulation. According to this method, the particular path or paths taken by the strongest signal is not important. The directional antennas may be used at one of or both the transmitter and receiver. At the transmitter, a directional antenna limits the number of paths that the transmitted wireless signal may take. At the receiver, a directional antenna reduces the number of paths from which wireless signal scan be received. In either case, the direct signal path can be strengthened in relation to the reflected or echo signals. However, directional antennas are inconvenient and have limited use because they must be oriented to direct or receive the wireless signals.

In wireless distance measurements, the problem is not to increase the signal to-noise ratio or bit error rate irrespective of signal propagation time or distance. The object is to identify the direct path signal as closely as possible. If reflected signals contribute significantly to the measurement, the resulting distance will be inaccurate.

Some solutions may be used to correct wireless distance measurements for inaccuracies caused by the multipath phenomenon. Moreover, some solutions are capable of determining the distance between two wireless devices using only the two wireless devices, as described in further detail below. To achieve this result, a first wireless device transmits a forward path signal to a second wireless device. The second wireless device generates a reverse-path RF signal sequence using the forward path signal such that the forward and reverse path signals are coherent. The reverse-path RF signal sequence includes different frequencies that have the same or substantially the same multipath characteristics.

Following is a summary of the main effects of multipath on distance measuring systems and the measures to take to counter it:

- Multipath signals will distort the distance reading to a degree depending on the strength and delay.
- The apparent delay in the presence of multipath can be corrected by analyzing the pass band amplitude and phase behavior to find relative strength and delay.
- The degree of resolution depends on the strongest received signal or the average of received signal for detection of the system.

4o ΚΕΦΑΛΑΙΟ

CHAPTER FOUR

IV

MATHEMATICAL METHOD FOR INDOOR LOCALIZATION

This chapter presents Location Estimation Based Inter tag Distance-MDS Algorithm for implementation in indoor environment. First, Multidimensional Scaling (MDS) Technique/Model are introduced with Measurement Model of Log-Distance Path Loss propagation, Low of cosine to measure the distance between RFID reader and tags based RSS, and Procrustes Analysis. Last, the Proposed Algorithm of a Probabilistic Model is illustrated with formula.

4.1. Multidimensional Scaling (MDS) Technique

Recently Multidimensional Scaling (MDS) has been successfully applied to the problem of node localization in wireless sensor networks. MDS technique has its origins in psychometrics and psychophysics. It is often used as part of exploratory data analysis or information visualization technique that displays the structure of distance. It is related to principal component analysis, factor analysis, and cluster analysis. The typical goal of MDS is to create a configuration of points in one, two, or three dimensions, whose inter-point distances are “close” to the known inter-point distances. Depending on the criteria used to define “close”, many variants of the basic MDS exist [30]. MDS has found many applications in chemical modeling, Economics, Sociology, political science and, especially, mathematical psychology and behavioral sciences [86]. More recently, MDS has been applied in many fields, such as Machine Learning [87], Computational Chemistry [88]. When used for localization, MDS can be applied to find a map of sensor positions in two or three dimensions when dissimilarities are measurements of range obtained, and take full advantage of inter-point distance information between sensors that have yet to be localized. Typical procedure of MDS algorithms involves first, computing the distance between all pairs of nodes to get the information that is used to construct a distance model (distance matrix) as the input for MDS, it's used the distance measurements to estimate the nodes positions. In wireless networks, nodes will prefer the shortest measured distance to estimate their positions relative to some coordinate system [88]. This will underestimate localization errors when the ranging error is beyond some value. For the isotropic networks, the localization error increases with larger ranging error. The entry (i,j)represents the distance along the shortest path between nodes (i,j), [89]. If only connectivity information is available, the entry (i,j) then represents the least number of hops between nodes i and j. Then MDS is applied to the distance matrix and an approximate value of the relative coordinates of each node is obtained.

There are several variants techniques of basic MDS algorithm in wireless sensor networks: MDS-MAP(C) [90], MDS-MAP(P) [91], MDS-Hybrid [92] and RangeQ-MDS [93] [94].We adopt classical MDS in this work, classical metric MDS is the simplest case of MDS: the data is quantitative and the proximities of objects are treated as distances in a Euclidean space. The goal of metric MDS is to find a configuration of points in a multidimensional space such that the inter-point distances are related to the provided proximities by some transformation. If the proximity data were measured without error in a Euclidean space, then classical metric MDS would exactly recreate the configuration of points.

4.2. Location Estimation Based Inter tag Distance-MDS Algorithm

4.2.1. Multidimensional Scaling Models

MDS models are defined by specifying how the given similarity data δ_{ij}between two objects i and j are mapped into distances d_{ij} of an m-dimensional MDS configuration X consisting of all objects. The mapping is specified by a representation function, $f : d_{ij} \rightarrow \delta_{ij}$which specifies how the similarity data should be related to the distances. In practice, one usually does not attempt to strictly satisfy f. Rather, what is sought is a configuration whose distances satisfy f as closely as possible. The condition "as closely as" is quantified by a badness-of-fit measure or loss function. The loss function is a mathematical expression that aggregates the representation errors,$e_{ij} = d_{ij} - \delta_{ij}(\chi)$, over all pairs ($i$, j). A normalized sum-of-squares of these errors define stress, the most common loss function in MDS.

Assume that measures of similarity, for which we use the general term proximity, δ_{ij} are given for each pair (i, j) of n objects. The localization problem is often formulated as an optimization problem that minimizes the sum of squared errors. This optimization problem is generally non-convex with many local minima. Traditional local optimization techniques, such as the Levenberg-Marquardt method [30], require good initial points in order to produce good solutions. Global search methods such as simulated annealing or genetic algorithms are generally too slow.

To solve this problem (or in this context), MDS is presented in this chapter, which it attempts to represent proximities by distances among the points (representing the objects) of an m-dimensional configuration X, the MDS space. Given a Cartesian space, one can compute the distance between any two points i and j. The Euclidean distance between points i and j in a two-dimensional configuration X, is computed by the following formula:

$$\delta_{ij}(x) = \sqrt{(x_{i1} - x_{i1})^2 + (x_{i2} - x_{i2})^2} \qquad (4.1)$$

This can be written as

$$\delta_{ij}(x) = \left[\sum_{a}^{2} x_{ia} - x_{ij}\right]^{1/2} \qquad (4.2)$$

MDS maps proximitiesd_{ij}, into the corresponding distances $\delta_{ij}(x)$ of an MDS space X. That is, f: $d_{ij} \rightarrow \delta_{ij}(x)$. The distances $\delta_{ij}(x)$ are unknowns, and MDS finds a configuration X of a predetermined dimensionality m on which the distances are computed. The function f, on the other hand, can be either completely specified or restricted to come from a particular class of functions. Empirical proximities always contain noise due to measurement imprecision. Hence, one should not insist, in practice, that $f(d_{ij}) = \delta_{ij}(x)$, but rather that$f(d_{ij}) \approx \delta_{ij}(x)$, where "≈" can be read as "as equal as possible". Computerized procedures for finding an MDS representation usually start with some initial configuration and improve it by moving around its points in small steps (iteratively) to approximate the ideal model relation $f(d_{ij}) = \delta_{ij}(x)$, more and more closely. A squared error of representation is defined by

$$e_{ij}{}^2 = \left[d_{ij} - \delta_{ij}(\chi)\right]^2$$

Summing ${e_{ij}}^2$over all pairs (i, j) yields a badness-of-fit measure for the entire MDS representation, *raw stress*

$$Str(x) = \sum_{i,j}\left[f(d_{ij}) - \delta_{ij}(\chi)\right]^2,$$

To avoid scale dependency, *Str* can be normalized as follows,

$$Str^2(x) = \frac{Str(x)}{\sum {\delta_{ij}}^2(\chi)} = \frac{\sum\left[f(d_{ij}) - \delta_{ij}(\chi)\right]^2}{\sum {\delta_{ij}}^2(\chi)} \qquad (4.3)$$

Taking the square root yields a value known as, $Str^2(x)$.

Let there be *M* points in a network, $X_i, i = 1, \ldots\ldots, M$, and let $X = [X_1, \ldots\ldots X_M]^2$. Here, $X\ is\ 2 \times M$. Let D=$[d_{ij}]$ be the matrix of pairwise distance measurements, where we consider the localization problem to be 2-dimensional, and d_{ij}, is the measured distance between X_i and X_j for $i \neq j, and\ \ d_{ii} = 0\ for\ all\ i$.

The goal of MDS is to find an assignment of *X* in low-dimensional space that minimizes a "stress function," as:

$$\bar{X} = \underset{x}{argmin}\, Stress\ (X) \qquad (4.4)$$

$$Str(X) = \sqrt{\frac{\sum(d_{ij} - \delta_{ij})^2}{\sum(\delta_{ij})^2}} \qquad (4.5)$$

Where δ_{ij} is the Euclidean distance between X_i and X_j . In Classic metric multidimensional scaling, the elements of $\bar{X}$can be computed using EVD of the double centered squared distance matrix.

Let the squared distance matrix is, $D^2 = [{d_{ij}}^2]$, when *X* contains the coordinates of M points in two dimensions, D^2 can be represented as,

$$D^2 = \begin{bmatrix} o & {d_{12}}^2 & {d_{1M}}^2 \\ {d_{12}}^2 & o & {d_{2M}}^2 \\ {d_{1M}}^2 & {d_{2M}}^2 & o \end{bmatrix}$$

The elements of the double centered squared distance matrix $B_{M\times M}$ are determined as,

$$b_{ij} = -\frac{1}{2}\left(d_{ij}^2 - \frac{1}{M}\sum_{k=1}^{M} d_{kj}^2 - \frac{1}{M}\sum_{k=1}^{M} d_{ik}^2 + \frac{1}{M}\sum_{k=1}^{M}\sum_{l=1}^{M} d_{kl}^2\right) \qquad (4.6)$$

$$= X_i^T X_j$$

Reformulating *Eq.(4.6)* in matrix notation

$$B_{M\times M} = -\frac{1}{2}J\,D^2J = X^TX \qquad (4.7)$$

Note that *B* is a positive definite matrix having m positive eigenvalues. *Eq.(4.7)*, is an expression for *X* in terms of *D*, in m-dimensional space,. We know that the measurements *D* originate from a 2-dimensional space. If the measurements from *D* are perfect, then there is a zero-stress assignment of *X*, when m-dimensional =2 (i.e., it turns out that Stress (*X*) must increase or stay the same; it cannot decrease). However, measurement error makes it unlikely that such an assignment really exists. Thus, some stress is inevitable as we reduce the dimensionality from *m* to 2 or 3.

As before, this dimensionality reduction is done by taking EVD of *B*, then removing eigenvalues and eigenvectors. This is a safe operation because *B* is symmetric positive definite, and therefore has *M* positive eigenvalues.

$$B = XX^T = UVU^T$$

$$X = UV^{-1/2} \qquad (4.8)$$

The problem is that *X* has too many columns, we need to find *X* in 2-space. To do this, we keep the two largest eigenvalues from *V* and the corresponding eigenvector leaving a 2×2 diagonal matrix. Then *X*, has the proper dimensionality.

4.2.2. Measurement Model of Log-Distance Path Loss propagation

In order to estimate the distance between a transmitter (i.e., RFID-tagged object or reference tag) and a receiver (RFID- reader) from RSS, the log-distance path loss model for indoor environment which describes the relationship between the signal attenuation and the distance, and that has been used extensively in the literature[77] [95]

$$PL(d_{tr}) = PL(d_0) + 10\,n\,log(d_{tr}|d_0) \qquad (4.9)$$

Where d_{tr} represents the distance between the transmitter and receiver, $PL(d_{tr})$ is a random variable describing the path loss measured in *dB* at distance d_{tr}, $PL(d_0)$ is the free space path loss for distance d_0, *n* is the path loss exponent which indicates the decreasing rate of signal strength in an environment;$d_0$is a reference distance normally chosen close to the transmitter tag. In *Eq.(4.9)*,the path loss measured in *dB* at distance d_{tr}can only be considered as an average value because does not consider the variable factors in the surrounding environment. To take the propagation parameters in this model, usually the received signal strength is log-normal Gaussian distribution. To represent a probabilistic approach and model the path loss measured in *dB* at distance d as a random variable *PL(d)* by using a Gaussian random variable $N(0, \sigma^2)$ as :

$$\overline{PL}(d) = \{\text{ Path loss model}\} + \{\text{Gaussian distribution}\}$$

$$\overline{PL}(d) = PL(d_{tr}) + Y \qquad (4.10)$$

Where Y is a random variable which follows a Gaussian distribution $N(0, \sigma^2)$, which is zero mean Gaussian random variable with variance σ^2-in dB, which reflects the variation, on average, of the received power that naturally occurs when a PL model of this type is used. Path loss is the main ingredient of a propagation model. It is related to the area of coverage of RFID systems [96]. In general, the exponent n is environment dependent, in free space, n is equal to 2, however, in more complicated environments, n will generally be larger. The pathloss model defines the received power at the receiver given the transmit power of the transmitter[21],i.e., with a given transmitting antenna power P_t transmitting antenna gain G_t , and receiving antenna gain G_r , the received signal strength $P_r(d_{tr})$-in dB at distance d is given by :

$$P_r(d_{tr}) = P_t + G_t + G_r - \overline{PL}(d) \qquad (4.11)$$

Where d_{tr} is a distance between a transmitter and receiver,

$$P_r(d_{tr}) = P_t + G_t + G_r - PL(d_0) - 10\, n \log(d_{tr} | d_0) - N(0, \sigma^2) \qquad (4.12)$$

$$K = P_t + G_t + G_r - PL(d_0) + 10\, n \log(d_0) \qquad (4.13)$$

Where K is a constant, because the first four terms in (4.12) are all constant. It equals the received signal at $d_0 = 1\ m$. So the above equation can be rewritten as:

$$P_r(d_{tr}) = K - 10\, n \log(d_{tr}) - N(0, \sigma^2) \qquad (4.14)$$

From Eq.(4.14) we can obtain the signal strength $P_r(d_{tr})$to estimate the distance between tag to reader from the measured *RSS* by the reader in-dB ,

$$d_{est}(P) = 10^{\frac{K - P_r(d_{tr})}{10\, n}} \qquad (4.15)$$

Fig.32, shows that received signals strength at tags and a path-loss model provide distance between the tags and reader, where the Path-loss models measure received signal strength as a function of distance.

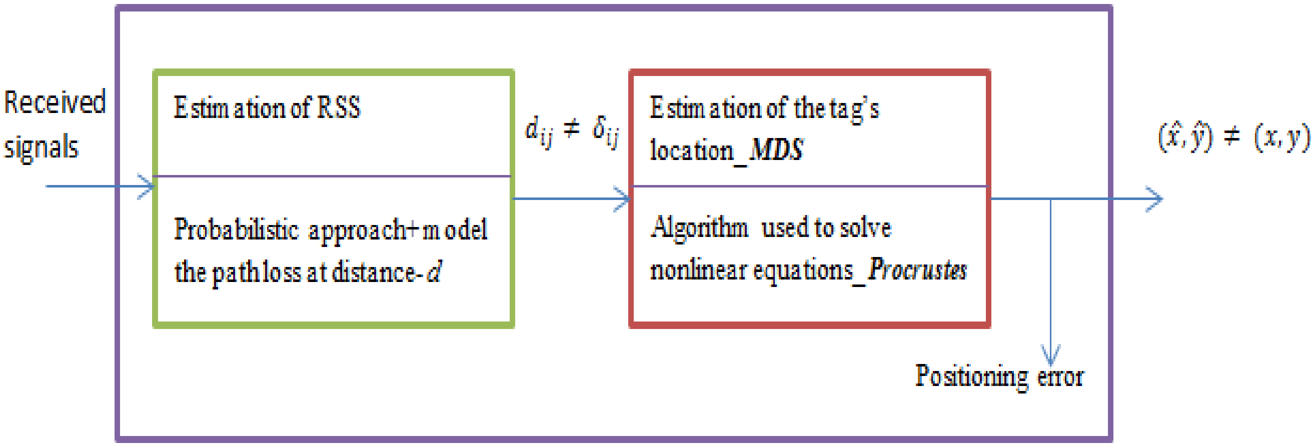


Figure 32: Path loss models measure received signal as a function of distance.

4.2.3. Approach of Inter Tag Distance Estimation

As pointed out earlier, the distance between the tags and the reader can be determined from the RSS values either at the tags end or at the reader end, and the Path-loss models measure received signal strength as a function of distance. Signal strength measurements are affected by various radio wave propagation. We denote the tag-to-reader distance between reader and tags (RFID-tag and the reference-points) to be d_{tr}. Given the RSS measurement P_{tr} from tags at reader, the tag-to-reader distance can be estimated using *Eq.4.16*, which measures the distances between the receivers (RFID-readers) and transmitter (RFID- active tags) using the large-scale path loss model. However, since a tag cannot communicate with another tag, we cannot use the same method to estimate the inter-tag distance. To solve this problem, we present the Law of Cosine to measure the distances between the RFID-tags, as shown in ***Fig.33.*** In order to calculate the position of objected tag, the distance E values are very important to calculate based on the distance between tags, calculated the inter-tag distance estimation in the detection area (indoor environment). This approach measures the inter-tags distance to construct the distance matrix as the input for MDS (for LANDMARC finds the unknown objecting tags' nearest neighbors, where RFID tags illustrate object tag and the reference-points) [38]. The reader is detected the distance between RFID tags is E. In this section, the following explanation elaborates conceptual working based on only one reader and two RFID tags for simplicity and clarity. If there are number of RFID tags, using these relations to estimate the inter-tag distance, then can obtain a set of distances between RFID tags, to locate the object. The distance between tag_i(first tag) and reader is, D_{ir}, the distance between tag_t(second tag) and reader is D_{tr}.

4.2.4. Apply the Law of Cosine

Let D_{ir}, D_{tr} and E be the lengths of the legs of a triangle, φ is the angle of tag_i, then the law of cosines states,

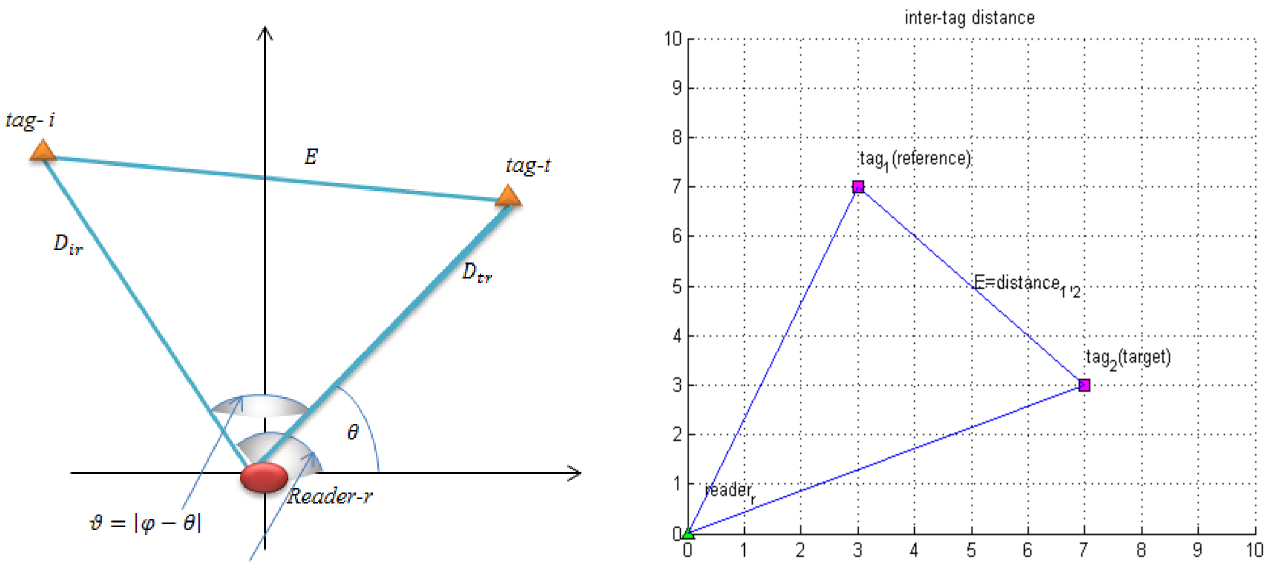
$$E^2 = D_{ir}{}^2 + D_{tr}{}^2 - 2\{D_{ir}\}\{D_{tr}\} \cos\varphi \qquad (4.17)$$

Solving for the cosines yields the equivalent formulas

$$\cos\varphi = \frac{-E^2 + D_{ir}{}^2 + D_{tr}{}^2}{2\{D_{ir}\}\{D_{tr}\}}$$

φ , Is the difference in angles formed by two linear vectors,

$$\varphi = \vartheta - \theta = absolute(\,\vartheta - \theta) \qquad (4.18)$$



(a) **(b)**

Figure 33: a, b: Distance measurement between inter-tags.

The distance E between RFID tags, that is calculated using trigonometric postulate of geometry. In triangle, if two sides and the angle opposite to the unknown side are known, then the unknown side can be found out [97].

By applying the Law that described above, can be obtained,

$$E = \sqrt{\{D_{ir}\}^2 + \{D_{tr}\}^2 - 2\{D_{ir}\}\{D_{tr}\} \cos\varphi} \qquad (4.19)$$

$$\varphi = \cos^{-1}[(\{D_{ri}\}^2 + \{D_{tr}\}^2 - \{E\}^2) / 2\{D_{ri}\}\{D_{tr}\}] \qquad (4.20)$$

After measuring the distance E, we can apply the MDS algorithm which constructs the distance matrix as the input. This approach is based on received signal strength (RSS) measurement reported by reader to infer the tag-to-reader distances and inter-tag distances estimation.

4.2.5. Procrustes Analysis

As described above, Classical MDS creates a configuration of points in one, two, or three dimensions *X*. The inter point distances of this configuration reproduce those of the original data points *Y*. However, they are in a relative coordinate to determine the absolute coordinate, the locations of the readers are needed to find an optimal transformation using *PA*. *PA* is a statistical procedure for comparing shapes. It is commonly applied to sets of landmark data, in which significant features in a population are measured as geometric locations. The analysis computes the best-fitting superposition of the landmarks in two data sets using a shape-preserving Euclidean transformation that minimizes variations in location, rotation and scale. It is often used as a preprocessing step for further statistical analysis. *PA* has its origins in the biological study of animal morphometrics, but has found application in areas as diverse as archeology, astronomy, civil engineering, geography, network design, and physical chemistry. The name comes from *PA*, a figure in Greek mythology noted for his proclivity for "shrinking" and "stretching" visitors to fit in his bed. It determines a linear transformation (translation, reflection, orthogonal rotation, and scaling) of the points in matrix X to best conform them to the points in matrix *Y*. The goodness-of-fit criterion is the sum of squared errors. *PA* returns the minimized value of this dissimilarity measure values to match points in matrix Y, by a measure of the scale of Y, given by:

$$\sum_{i,j}^{n} (Y_{ij} - A_{ij})^2 \qquad (4.21)$$

Where A is replicates the array x on an n-times-n tiling, to create a matrix X that has n times as many rows and columns as Y. The output X will match Y in all remaining dimensions. That is, the sum of squared elements of a centered version of Y, can be implemented in MATLAB as [98],

```
d = procrustes(X,Y) % determines a linear transformation
% procrustes returns the minimized value of this dissimilarity measure
in d.
sum(sum((X-repmat(mean(X,1),size(X,1),1)).^2,1))
[d,Z] = procrustes(X,Y) % also returns the transformed Y values.
```

4.3. The Proposed Algorithm of a Probabilistic Model

We introduced algorithm an indoor location to estimates objects' locations based on RSS measurement by measuring the tag-to-reader distances provided by the readers to construct the distance matrix as the input for MDS to locate RFID-object tag (unknown tag), the data available in the simulation are the RSS measurement because RSS information can be obtained at no additional cost with each radio message sent and received. However, signal strength based *RF* localization systems suffer from the inherent errors associated with the *RF* propagation, the RSS may not follow the model exactly due to multipath propagations and some other factors. These effects cause random variations of the RSS, because the indoor radio signal can follow multiple paths between a transmitter (i.e., tagged object or reference tag) and a receiver (i.e., reader). Thus, to take these factors into consideration in order to enhance the location estimation of the object tag, and to alleviate the limitations of RF and the process measurement noise on the location estimation. In this context, and from the probabilistic approach and path loss model, we present a model to observe the effect of propagation parameters on the estimated distance, which can observe the probability distribution of estimated distance between tags and reader and how the estimated distance affects by these parameters.

RSS effects on the estimated distance between tag-to-reader and inter-tag distances based on the tag-to-reader distance information, which means, RSS measurement error will be affected on the location accuracy of tags. RSS usually demonstrates a Gaussian normal distribution [32].

In this model we can have the distribution of the estimated distance relative to propagation parameters, it has been shown that, the *pdf* of a certain value of $P_r(d_{tru})$of tag_i reported by $reader_j$,where the distance between reader and the transmitter is d_{tru}(we can read the true distance between tag_i-to-reader), and the *pdf* of a certain value of estimated distance,$(d_{est})$of tag_i reported by $reader_j$, where the distance between it and the transmitter is d_{est} . A more realistic assumption is the propagation parameters impact on the received signal strength, which leads to affect the estimated distance between the tags and reader.

In order to calculate the probability P($\mathrm{P_r(d_{est})}$, we calculate the propagation parameters to observe the effect of these parameters on the estimated distance, which will decrease the localization accuracy. Due to the effective of the path loss on the tags' signal strength reported by $\mathrm{reader_j}$ at $\mathrm{tag_i}$ in indoor area. The propagation parameters $\mathrm{n_j(i)}$ and $\mathrm{K_j(i)}$ at each $\mathrm{tag_i}$ reported by $\mathrm{reader_j}$ can be calculated by (4.22) and (4.23) respectively

The propagation parameters $n_j(i)$ and $K_j(i)$ at each tag_i reported by $reader_j$ can be calculated as,

$$n_j(i) = \frac{RSS_j(i) - PS_j(i)}{10 \log d_{ij}} \tag{4.22}$$

Where PS, is the RSS value when close-in reference distance measured at 1m

$$K_j(i) = RSS_j(i) + 10\, n_j(i) \log d_{ij} \tag{4.23}$$

Where $i \neq j$.

From Eq.(4.14), $\mathrm{d_{ij}}$ is a true distance between $\mathrm{tag_i}$ and $\mathrm{reader_j}$, the signal strength- $\mathrm{P_r(d_{ij})}$ is a Gaussian random variable with mean and variance (μ,σ^2), the probability function of $\mathrm{P_r(d_{ij,tru})}$, is as follow

$$P(P_r(d_{ij,tru}))=\frac{1}{\sqrt{2\pi\sigma}} \exp\left(\frac{-(\mathrm{P_r}(d_{ij,tru})-\mu)^2}{2\sigma^2}\right) \tag{4.24}$$

Where μ is a mean, we can substitute the propagation parameters $K_j(i)$ *and* $n_j(i)$for the meanas,

$$\mu = K_j(i) - 10\, n_j(i) \log(d_{ij,tru})$$

We can substitute the propagation parameters$K_j(i), n_j(i)$for the distribution of the estimated distance-$d_{ij,est}$ is given by,

$$P(d_{ij,est}) = \frac{1}{d_{est} \ln 10\sqrt{2\pi\sigma}} \exp\left(\frac{-(10 n_j(i) \log(d_{est}/d_{tru}))^2}{2\sigma^2}\right) \tag{4.25}$$

The RFID- tag to reader distance estimate $d_{ij,est}$ defined by *Eq.(4.15),*

$$d_{ij,est} = (d_{ij})_{tru} 10^{\frac{K_j(i)}{10\, n_j(i)}} \tag{4.26}$$

Where $d_{ij,est}$, is the tag-to-reader distance estimation using log-normal path loss model from RSS measurement.

After measuring the propagation parameters which effect on the probability function at each tag_i, the signal has to take multiple paths to travel between transmitter and receiver in indoor area. RFID system is NLoS characteristic random multiple path radio propagation [30]. When obstructions are encountered, the signal has to take multiple and the signal reaches to the receiver through different paths each having signal strength pattern with interference. The shortest path that a wave can take is the unobstructed path, i.e., Multipath interference is avoided by selecting the strongest/maximum received signal for detection between receiver and transmitter, and RSS may have been dropped almost the RF-interference, because the RSS has an inverse proportional relationship with a distance from receiving station and the maximum RSS that will be leaded to decrease a measurement error of location estimation.

According to this property, we model the ratio of the effective path loss on RSS for RFID tags in the detection area which is determined by the reader. To alleviate the measurement error on the location estimation and the process measurement noises on the location estimation, we proposed model based on knowledge the effective path loss on the received strength for the tags in the coverage area. We measure the received signal, which has Maximum RSS relative to Minimum PL(*Max RSSPL*) on RFID tags, that can be enhanced the measured RSS from effects of multipath distortion. Hence, can be enhanced the object location estimation by measuring the *Max RSSPL* at each locating tags.

We consider the propagation parameters in *Eq.4.14,* which cause received signal strength measurement errors. From the *Eq.4.24,* it calculates $P(\, P_r(d_{ij,tru}))$ at each RFID-tag to observe the *pdf* of received signal reported by RFID-reader in order to estimate the object's location. To observe $P(\, P_r(d_{ij,tru}))$ from *m* reader at tags location $\mathrm{x}\{\mathrm{P_j}((\mathrm{d_{ij,tru}}), \mathrm{x}))\}$, can be represented as,

$$P(P_j(d_{ij,tru})) = \prod_{j=1}^{m} P(RSS_j(i))$$

To measure the received signal, which has Maximum RSS relative to Minimum PL(Max RSSPL) at a certain distance on each tag, can be calculated as,

$$P_j(\,RSS_{str}) = P_j(MaxRSSPL, d_{ij})$$

$$Max\ RSSPL_j(i) = \sum_{j}^{m}\sum_{i}^{n} 10\ log10\left(\frac{P_j(i) - PL_j(i)}{P_j(i)}\right) \qquad (4.27)$$

From Eq.4.27, can be calculated the estimated distance to observe the propagation perimeters on estimated distance ,

$$\Delta_{est,ij}(Max\ RSSPL) = 10^{\frac{K_j(i) - Max\ RSSPL_j(i)}{10\ n_j(i)}}$$

Where $\Delta_{\mathrm{ij,est}}$, is a tag to reader distance estimation from Max RSSPL measurement. When MDS aimed at minimization the squared error between the squared distance, which tends to reduce the measurement errors, resulting in poor noise performance, and the stress function implies to view of the location problem (i.e., the sensor positions are estimated by minimizing stress), it can be found the distance estimation of Max RSSPL for the MDS stress function as minimizes a stress function according to Max RSSPL,

$$= \underset{x}{argmin}\sqrt{\frac{\sum(\Delta_{ij} - \delta_{ij})^2}{\sum(\delta_{ij})^2}} \qquad (4.28\,)$$

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CHAPTER FIVE

V

EXPERIMENTAL RESULT AND COMPARISON TO SIMULATED DATA

This chapter constitutes of two sections: 1) RFID identification tags. It presents the Identification of Employees in National Technical University of Athens (IE-NTUA), 2) Simulation of RFID localization tags based on Multidimensional Scaling (MDS) depends on RSS and our proposed Max RSSPL are preceded in these simulations to measure the tags' position. MDS method only using distance information between tag to reader distances from the received signal strength measurement, and inter tags distances based on the tag-to-reader distance information. The simulation compares the result of simulated data based localization to measured data based localization.

5.1. RFID -Tags Identification

This section illustrates the identification of employees in National Technical University in Athens, when the employees access to a certain area of the building (enters and leaves to/from the college), RFID applied for identification by offering special badges containing RFID-tags.

5.1.1. The Procedure of RFID Identification in NTUA

Identification of Employees can be performed utilizing RFID technology that is applied to the tracking by offering special badges which are contained RFID tags. The tags interact with NTUA information system. ***Fig.34***, shows the layout of entrances of NTUA which represents the house of RFID-reader system to read a data. Reader monitoring for enters and leaves of the employees in the building, (i.e., access to a certain area of the building), In effect, the data set is a record when the reader has read RFID-tags, and therefore, an employee's data records are the history of where and when the employees moved through the building.

RFID tags are adhesive devise which are placed on ID to be identified. When RFID-tags enters into the field of RFID antenna, they detect the activation signal, then they send certain information (based on the system setup) to the transceiver. The passive tags which are used by the RFID system do not require internal batteries and will last forever if not mistreated when employee access to a main doorway of the building, the data was collected from the RFID-tags which are used by the School of Computing and Information Systems at NTUA. A data set recorded when the employees have attempted to gain access to a main doorway of the building using RFID-tags and the data therefore characterizes the behavior of employees (RFID-tags) within this system.

The passive tags use the reader emissions to power a response that is usually an identification number. These tiny tags help employees reduce administration time and more importantly keep status by storing a full academic record. RFID tags can be supplied by special badges with a tamper mechanism to prevent from being removed or to emit a signal if attempted to be removed. The RFID-reader would be placed in specific area of a main doorway of the building in college during the employee will be located within a measurable distance. The measurable distance would be defined in the system integrator. Different materials also have an effect on the reading range and the possibility to read. Metal and water are two substances, which makes it difficult to read tags. The radio waves are absorbed by water and bounce off metal when using UHF. Low- and high frequency work better on products with water and metal than UHF and Microwave. One drawback is that the reading range decreases when using the lower frequencies.

5.1.2. Identification Case Study

The environment consists of a sensing network that helps the identification of employees/object tags within certain accuracy and enables the wireless communication between RFID-reader and tags.

Our RFID system comprises a passive RFID-tag and the Alien ALR-8800 RFID-reader at 865.7 MHz is designed to read and program EPC and issue event reports to a host computer system. RFID-tag collects data from the transmitter signaling at frequency, and sends it to an RF receiver. ***Fig.35,*** radios are pervasive in WSNs, and adding an accurate ranging feature would enable location aware networks in ways that are not possible using other technologies [14]. The no contact and NLoS nature of this technology are significant advantages common among all types of RFID systems. All RF tags can be read despite extreme environmental factors (this study was carried out in an open field to avoid the interference of the RF noise), they can also work at remarkable speeds. In some cases, tags can be read in less than a 100 milliseconds. The other advantages are their promising transmission range and cost-effectiveness. The range that can be achieved in an RFID system is essentially determined by:

1. The power available at the reader/interrogator to communicate with the tags.
2. The power available within the tag to respond.
3. The environmental conditions and structures (the former being more significant at higher frequencies including signal to noise ratio).

The field or wave delivered from an antenna extends into the space surrounding it and its strength diminishes with respect to distance. The antenna design will determine the shape of the field or propagation wave delivered, so that range will also be influenced by the angle subtended between tags and antenna. In space free of any obstructions or absorption mechanisms, the strength of the field reduces in inverse proportion to the square of the distance [15]. The major configuration values of software:

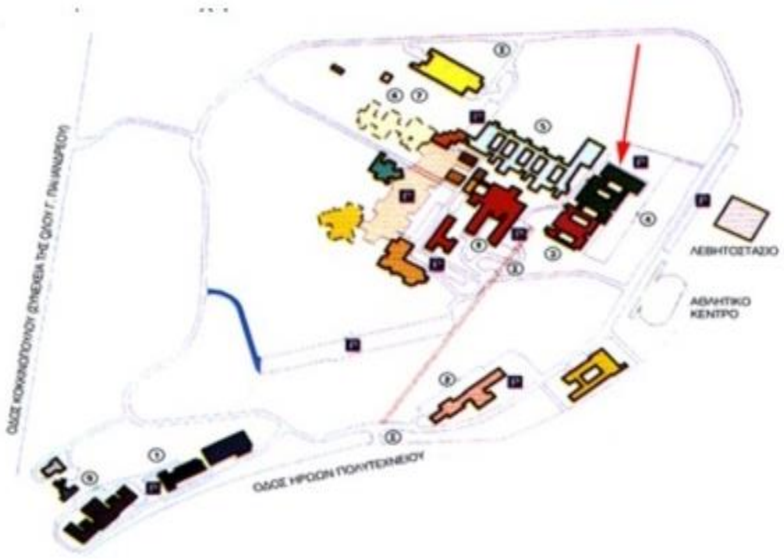


Figure 34 : NTUA Sitemap.

Figure 35: RFID System (the Alien ALR- 8800 RFID Reader).

1. Device (RF readers) setup: Used for configuring the IP addresses of the RF readers.
2. Range Used for specifying what range for tags is to be scanned.
3. Continuous mode: The reader will continuously report the tag ID as long as it was in the configured range.

5.1.3. Data Set Description

Table.11, shows the data records, ***Fig.36,*** show the menu research program of RFID-tags identification. Each record represents a single event, the outcome of when an employee presents a tag to the reader. RFID-reader generates one data record each time it attempts to read tags. A data record is a space-separated set of attributes and corresponding data values. i.e., data record specifies tag number 9806 as follows:

1. It was granted access (enter) through the doorway by RFID-reader on date 9/2/2012 and at time 09:15:51AM.
2. It was granted access (leave) at time 12:33:12 PM and it was granted access (enter) at time 01:10:11 PM.
3. It was granted access (leave) at time 04:01:05 PM.

5.2. Simulation of Localization Measurement for RFID-Tags

This section illustrates the simulation of RFID-tags localization based on Multidimensional scaling (MDS), and shows how the accuracy is computed in this simulation. In this simulation we present an indoor location sensing system for RFID-tagged objects based on MDS algorithm, where the data available in the RFID system are the RSS measurements from all the active tags reported at the reader, to measure the tag to reader distances and inter tag distances estimation in order to construct the distance matrix as the input for MDS algorithm, in order to estimate the target location.

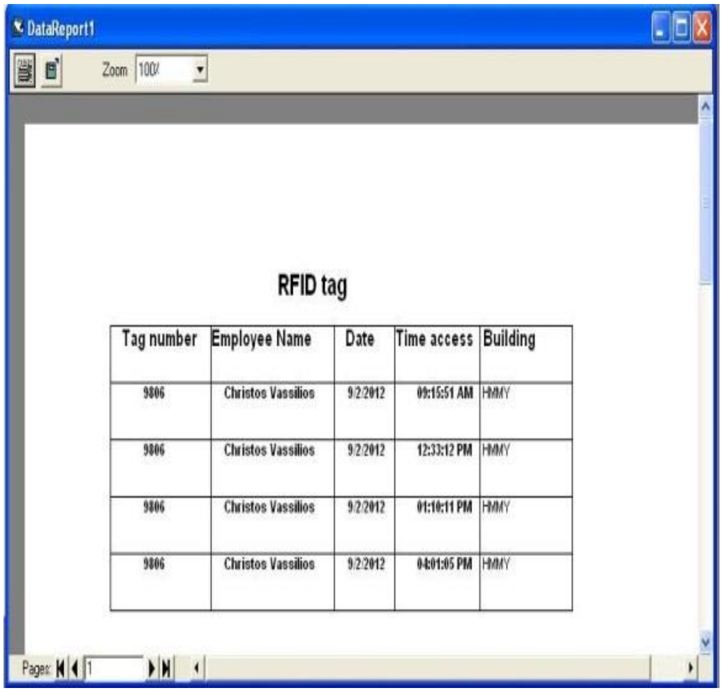
The detail explanation about our simulation is, Firstly, we assume that the data available in the RFID, are the RSS measurements from all the active tags reported at the reader, to measure the reader to tags distance and inter tags distance in order to construct the distance matrix as the input for MDS algorithm, in order to estimate the target location. The detail explanation about our simulation is, and RFID sensing network that measures the RSS information from the active tags, a communication network that enables the transmission and processing of the location information. Finally, the tracked object will be attached with a unique active RFID tag used for locating the object and reference tags also have unique IDs, where they are used for calibrating environmental parameters relative to RSS, the RFID reader reading IDs and issue event reports to a host computer system.

To evaluate the performance of our localization algorithm, the simulation studies in 10 m × 10 m square area, which choose the communications range of the active tag with a minimal range of 20 meters and maximum range of 50 meters, and the RFID-reader can provide RSS readings for each tag within its range, i.e., all the tags in the area can communicate with the readers. The in-building path loss model chosen for the purpose of simulation is given in *Eq.4.10*, the power of interrogation signal is 32dB. In *Eq.4.14*, the propagation parameters which cause received signal strength measurement errors are affected by zero mean Gaussian random noise, and the path loss exponent n is assumed to be 2. The topologies of the simulation will be generated randomly, the simulation run 200 attempts to compare the average location errors of the localization algorithms, and the results are achieved in figures. According to our assumption,

Table 11: Data Record Attributes.

Tags	Time	Access	Date
9027	08:33:33 AM	pass	9/2/2012
9030	09:03:10 AM	pass	9/2/2012
9034	08:50:23 AM	pass	9/2/2012
9806	09:15:51 AM	pass	9/2/2012
9808	09:10:39 AM	pass	9/2/2012
9030	11:19:44 PM	pass	9/2/2012
9806	12:33:12 PM	pass	9/2/2012
9806	01:10:11 PM	pass	9/2/2012
9027	03:30:11 PM	pass	9/2/2012
9030	03:45:45 PM	pass	9/2/2012
9034	03:55:23 PM	pass	9/2/2012
9806	04:01:05 PM	pass	9/2/2012

Figure 36: RFID-tags Data Identification.



RFID tag

Tag number	Employee Name	Date	Time access	Building
9806	Christos Vassilios	9/2/2012	09:15:51 AM	HMMY
9806	Christos Vassilios	9/2/2012	12:33:12 PM	HMMY
9806	Christos Vassilios	9/2/2012	01:10:11 PM	HMMY
9806	Christos Vassilios	9/2/2012	04:01:05 PM	HMMY

all the information reported by the RFID readers will be processed at the host computer. It(computer) will estimate the location of the objects (to the readers) according to the tag-to-reader distances from the RSS measurements and to estimate the inter-tag distances based on the tag-to-reader distance information. Since LE computes as the distance between the estimated and the actual tags position, and the average LE indicates the average error distance between estimated and actual tags position, can be represented as

$$er = \sum_{i=1}^{n} {\|l\|}/{|q|}$$

Where l, is the deference between the estimated and actual tags position, q, is the number of tags in our simulation, and $\|l\|$, is a vector norm. In addition, we normalize this error by the communications range of a tag.

5.2.1. Simulation 1: Impact of the propagation standard deviation on the localization accuracy

In this simulation investigates how the accuracy of location estimation would be affected by the value of the standard deviation of RSS for Multilateration [45][32], Landmarc [38] and MDS, when the different standard deviation of received signal ranges from (3 – 7) dB in the log-normal path loss model (4.14), It can be seen that the localization accuracy decreases(i.e., average localization error increase) for Multilateration, Landmark and MDS as the standard deviation σ increases because of the RSS measurements noise increases. Clearly, the larger values of σRSS degrade the accuracy dramatically, this is apparent from ***Fig.37***. The results suggest that the standard deviation of RSS has an inverse proportional relationship with the localization accuracy. In the same context, it is concluded that the performance of the MDS based on *Max RSSPL* is the best among the Multilateration and Landmark algorithms.

5.2.2. Simulation2: Impact of the Propagation path loss exponent on the localization accuracy

In this simulation investigates how the accuracy of location estimation would be affected by the value of the exponent path loss. When the *pathloss exponent* ranges from (2 – 7), the average localization error decrease slightly for Multilateration, Landmarc and MDS as the path loss exponent increase as shown in ***Fig.38***. It is concluded that the path loss exponent is almost consistent for Multilateration, Landmarc and MDS, it has an inverse proportional relationship with the localization error.

5.2.3. Simulation 3: Simulation Performance

The environmental parameters characterize the severity of the indoor space. The average LE is due to the propagation parameters, where the position estimation error is due to the algorithm does not match well between the estimated distance and actual distance ($f(d_{ij}) = \delta_{ij}(x)$), which leads to decrease the localization accuracy. From ***Fig.37,*** concludes that the average LE increases as the standard deviation-σ increase, which leads to decrease the localization accuracy. From ***Fig.38***, concludes that the average LE decreases as the path loss exponent, *n*, increases, which also leads to decrease the localization accuracy.

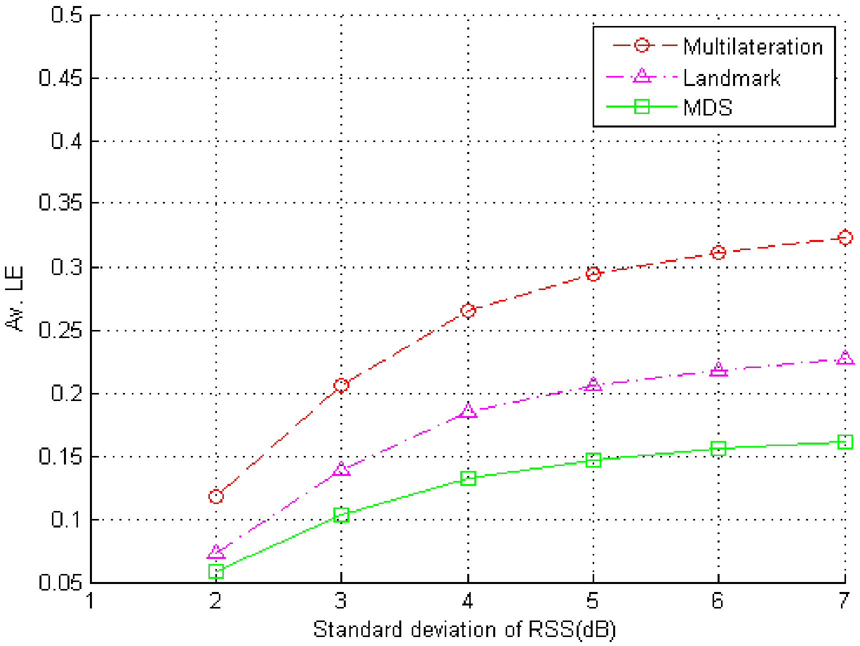


Figure 37: Propagation standard deviation for Multilateration,Landmarc and MDS algorithms.

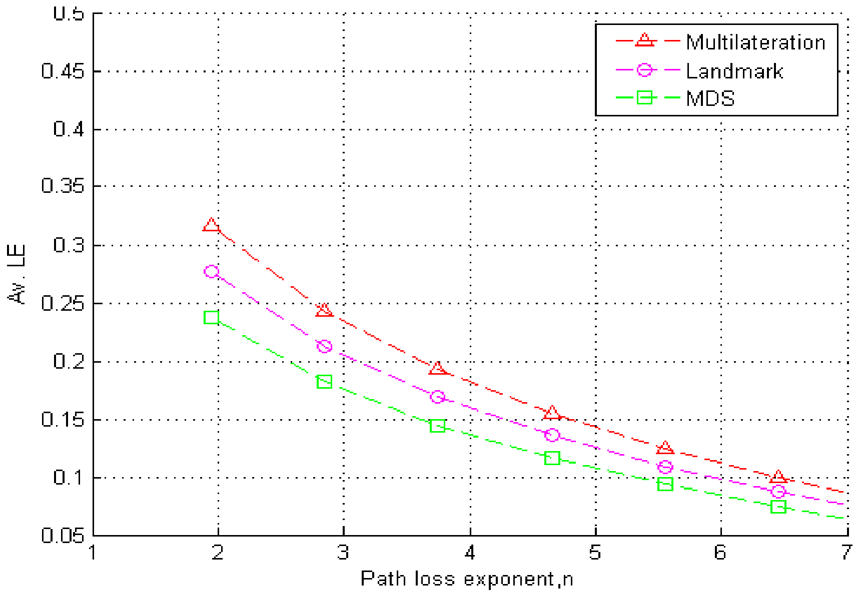


Figure 38: propagation path loss exponents for Multilateration, Landmarc and MDS algorithms.

From the probability model of estimated distance defined in (4.26) illustrates the effect of standard deviation and exponent pathloss. It is observed from ***Fig.39***, that when increasing the actual distance between tags and reader , or increasing the standard deviation or decreasing pathloss exponent, the spread of the probability distribution of estimated distance is dramatically increased, which means the probability distribution will be flat, i.e., when the distance between RFID tags and reader increases, since the longer transmission distance is, the bigger the gap between the true distance and the estimated distance is, and also it can be seen that the effect of the propagation parameters on the probability distribution of estimated distance. Therefore, analyzing the effect of propagation parameters on the precision of the RFID tags location will describe the accuracy of location estimation is decreased by effecting on the RSS measurement

5.2.4. Simulation 4: Impact of the Error Distance on the Localization Accuracy.

To study the impact of the *ED* between the estimated and the actual tags position on the localization accuracy. ***Fig.40***, illustrates the difference distance between the estimated and the actual tags position (was estimated with MDS). It can be seen that the localization error increases as the difference between the estimated and the actual tags position increases, that leads to reduce the localization accuracy of the estimated tags. i.e., the error distance has an inverse proportional relationship with the localization accuracy, Results obtained at each estimated tags position. However, ***Fig.41***, illustrates the *ED* between the estimated and the actual tags position is reduced when the tag to reader distance estimate depends on *Max RSSPL* measurement.

Clearly, when applied MDS algorithm based on *Max RSSRPL*, the *ED* between the estimated and the actual position of the tags achieves low localization error. It is observed from ***Table.12,*** that the *ED* of the tags becomes longer, which reduces the localization accuracy. Since the accuracy of location estimation depends on a close distance calculated between the estimated and the actual tags position.

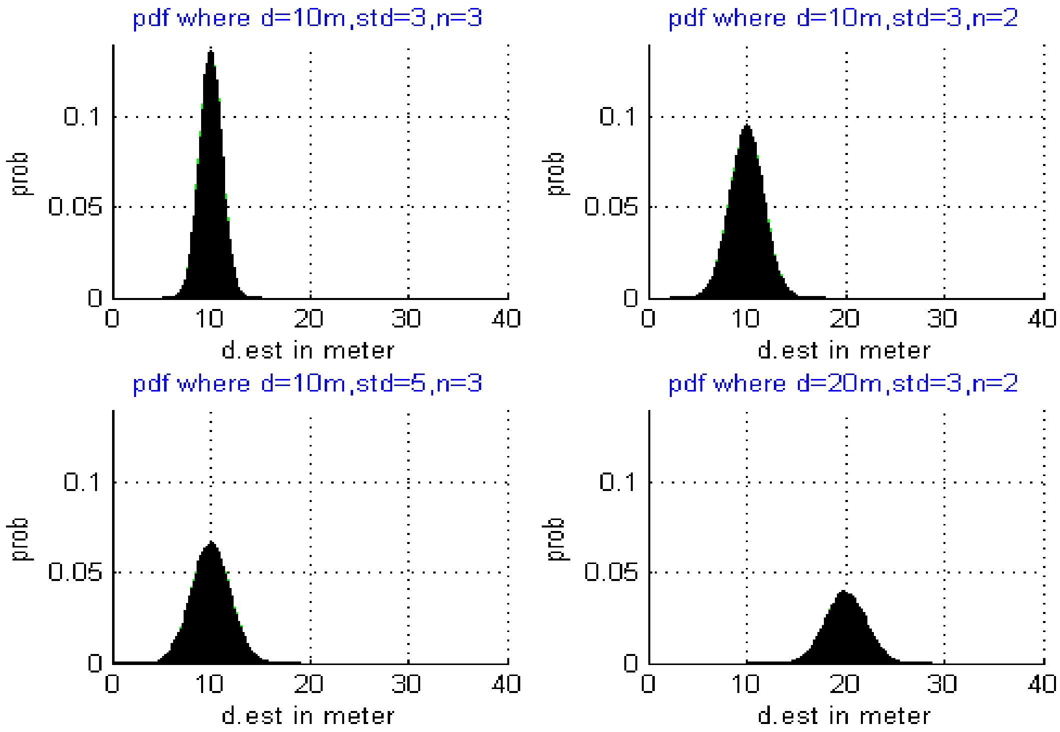


Figure 39: Probability distribution of estimated distance.

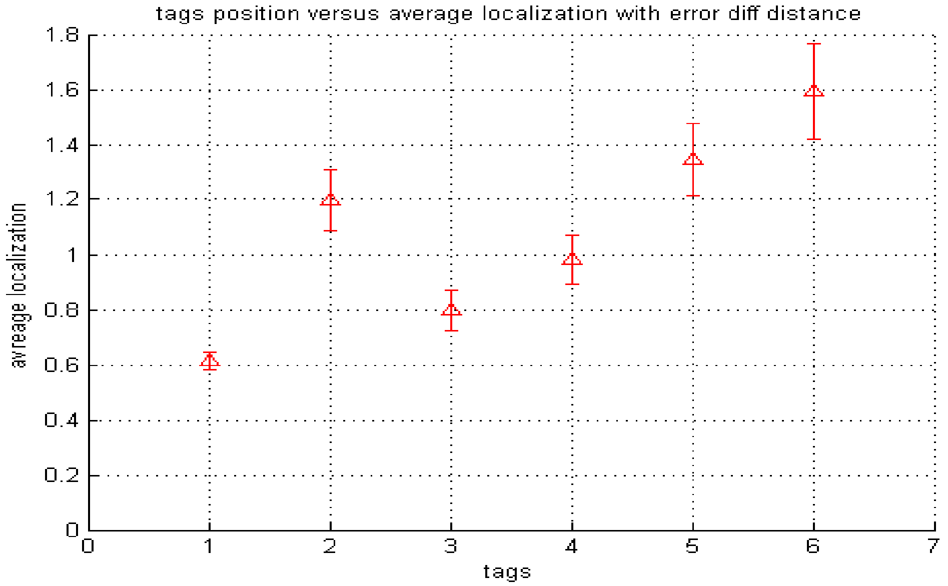


Figure 40: Tags position vs. average LE.

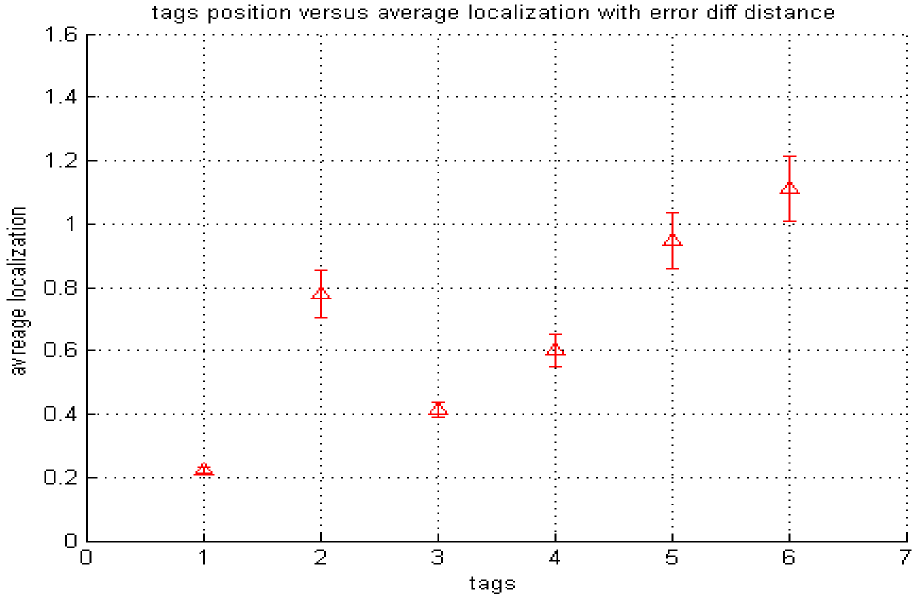


Figure 41: Tags position vs. average LE based on our refinement.

In consequence, measured *Max RSSPL* has higher possibility to get smaller error between the estimated and the actual tags position. We conclude that for greater accuracy should be measured the smallest *ED*, in this way, when the MDS depends on the *Max RSSPL* measurements from all the active tags to construct the distance matrix would contribute in reduction of the localization error's calculation of an object tag’s position and measured the smallest distance between RFID-tags and reader, which means maybe there is no or little obstructions are encountered for this distance as shown in ***Fig.42***, the signal has not taken multiple paths to travel from the transmitter to the receiver in indoor place, which leads to reduce the impact of the propagation parameters on the localization accuracy and help MDS algorithm to reduce the error distance between the estimated and actual tags position, as well as to estimate the accurately position of tracked tag, i.e., the propagation parameters increase the uncertainty accuracy of localization estimation for the tracked tag. This is apparent from ***Fig.43***.

5.2.5. Impact of Stress Function Value on the Dimension Number

Stress indicates the difference between the input proximities and the output distances in the n-dimensional. Stress function values lay between zero and one, the smaller the stress function is the better model for the input data. That is, whether the number of dimensions can be reduced from n-dimensional to two or three. The eigenvalues returned by MDS, in this case, a scree plot of those eigenvalues indicates that two dimensions are enough to represent the variables in order to obtain the best fit with the smallest number of possible dimensions. High stress may also result from errors in measurement and sometimes the original data may need to be re-examined, that is apparent in ***Fig.44.***

Table 12: Comparison of ED between the MDS algorithm Depends on RSS and Max RSSRPL.

MDS depends on:	***PED on Tag1***	***PED on Tag2***	***PED on Tag3***	***PED on Tag4***	***PED on Tag5***	***PED on Tag6***
1. RSS	***1.2***	***1.8 m***	***1.3 m***	***1.5 m***	***2.2 m***	***2.5 m***
2. Max RSSRPL	***0.8 m***	***1.2 m***	***0.9 m***	***1.1 m***	***1.3 m***	***1.5m***

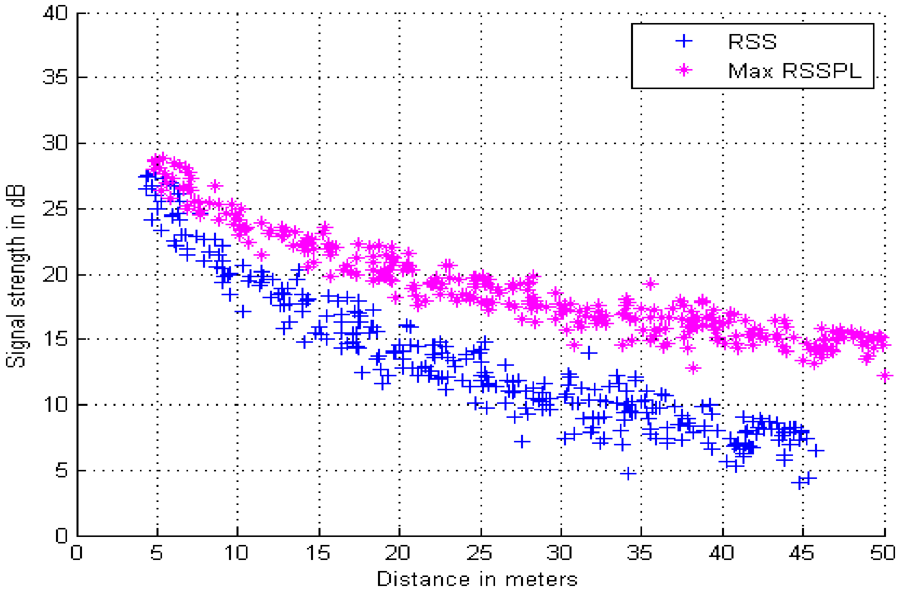


Figure 42: RSS, Max RSSPL vs. distance.

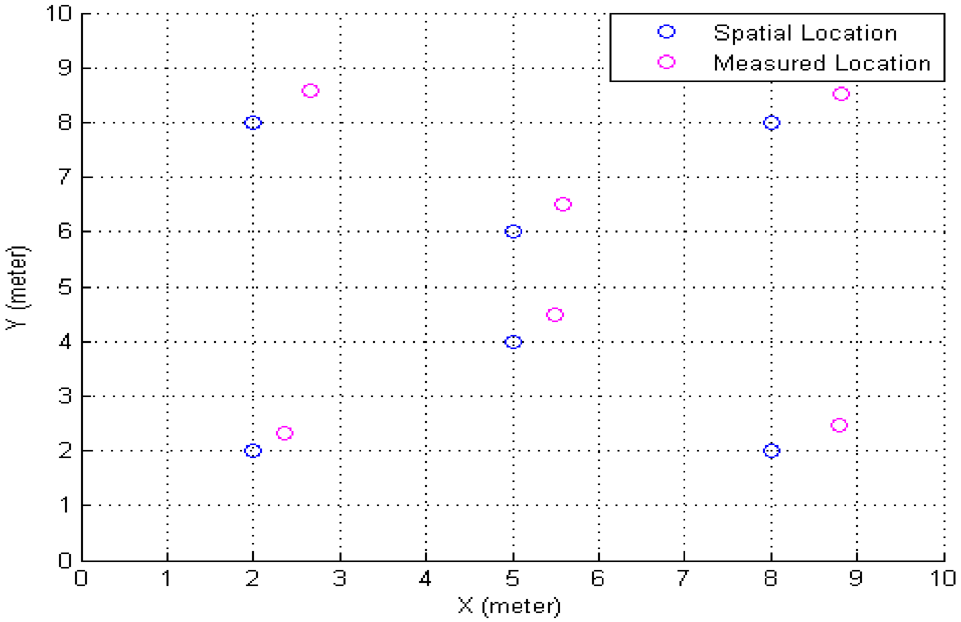


Figure 43: Spatial and measured location of tags

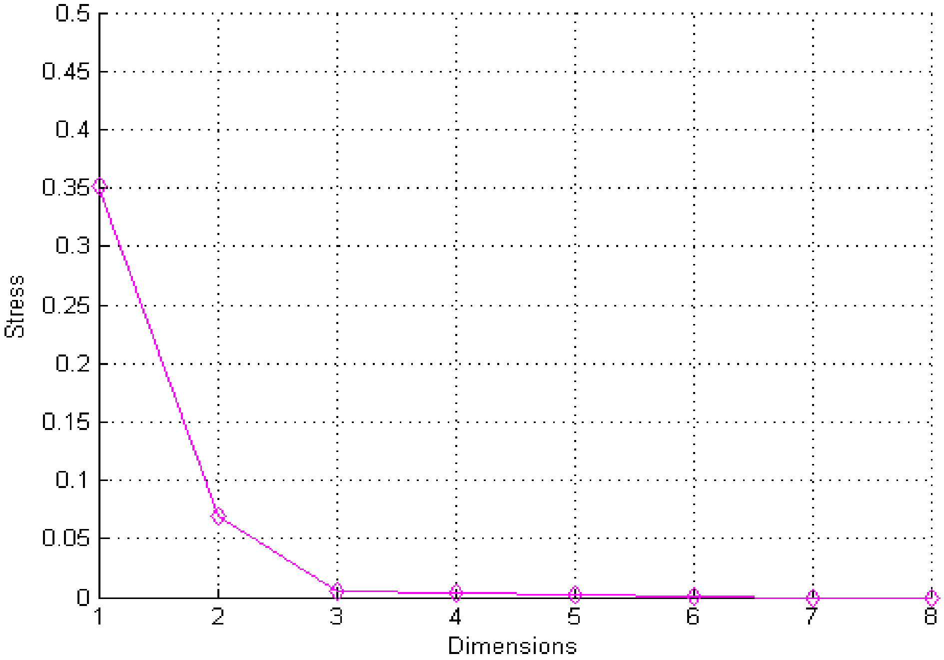


Figure 44: Scree plot.

5.2.6. Comparing Algorithms

Fig.45, shows the Cumulative Distribution Function of the precision for the different algorithms. Indeed, the algorithms have a wide variety of precisions. The cumulative distribution of the localization error for the comparing algorithms illustrates in *Fig.45*, it shows that the MDS depends on *Max RSSPL* provides a better performance compared with Multilateration and LANDMARC algorithms. What is more, the greatest localization error of the Multilateration algorithm may be very large, while the error of our proposed is much smaller. It is obvious from the figure that MDS based *Max RSSPL* gives more accurate localization results of the RFID tags than the other algorithms.

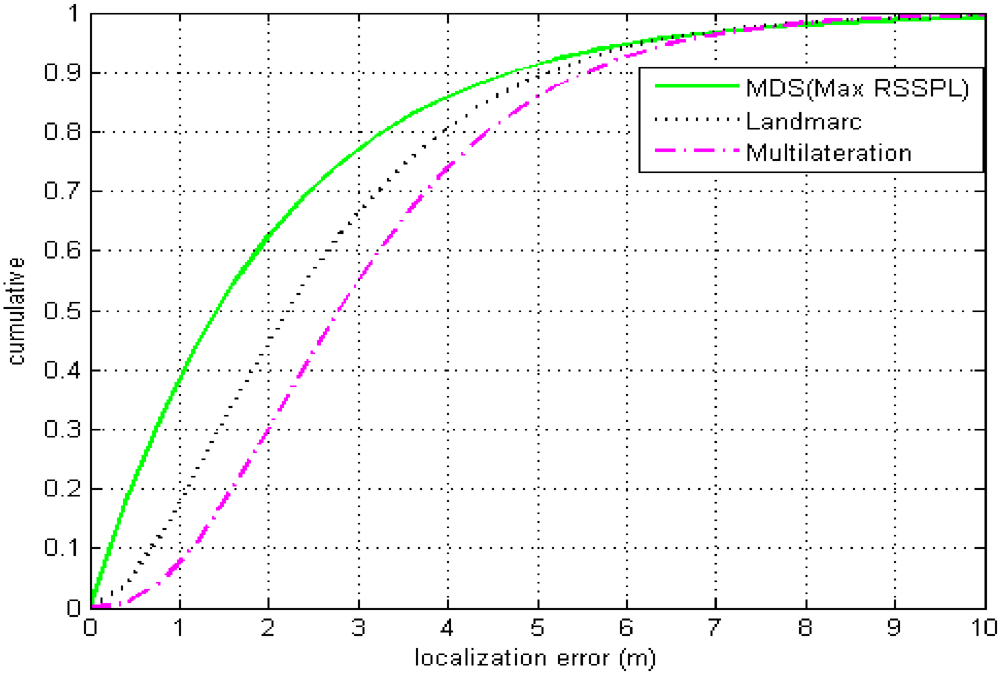


Figure 45: Cumulative distribution of the localization error for MDS (MaxRSSPL), Landmarc and Multilateration.

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CHAPTER SIX

VI

6.1. Conclusion

Throughout this dissertation, and after reviewing the applications presented in this work, one main conclusion is that WSNs and RFID are interesting and complementary, because they were originally designed with rather different objectives (RFID for identification while WSNs for sensing). In addition, WSNs uses a variety of sensors like the ones that were mentioned previously in chapter one, but they cannot identify objects individually while RFID allow the identification of items like container, pallet, boxes or bottles, etc. A localization using RFID has been explained theoretically and a simulation regarding the localization under certain scenario has been implemented. The RFID sensors are widely used to implement ubiquitous computing and smart spaces with the capability of providing received signal information current advanced RFID systems have become a potential candidate for mass localization.

In the theoretical part, Chapter one and Chapter two, presented the structure and the application of wireless sensor nodes and RFID have been introduced respectively.

In Chapter three and Chapter four, presented the characteristic of the ranging technology and the localization algorithms respectively in the theoretical part.

In Chapter five, presented the identification of employees in national technical university of Athens, and also provided the indoor simulation results to observe the characteristic of the localization algorithms that described in the theoretical part.

This combination of automation, identification, integration and increased accuracy has drawn attention to RFID in the employee's identification for the benefits of reduced administration time, automation of security, auditing, identification performance statistics or all of the above and reduction in any procedural errors by using a full normal record .

The data set characterizes the behavior of employees within the system as a tag acts as a surrogate for an entity. This data would be useful in analyzing the behavior of employees within RFID system. The RFID applications of employee identification are have more impact in situations where attendance in the university needs to be monitored. The basic advantage of RFID tags over barcodes is that can write on these tags and automatically read many tags simultaneously even if we can't see them.

As pointed out earlier, propagation parameters in indoor environments make working with signal strength measurements challenging, where the localization results have been observed by varying the propagation parameters first, an error distance between the estimated and the true positions of a tag later. A localization result based on simulated data for Multilatration, LANDMARC and MDS algorithms is compared to measure the accuracy of localization estimation of RFID tags. The most significant result proven through Chapter five that is the MDS can be said to be more suitable and outperforms that of Multilatration and LANDMARC. Moreover, the localization results based on *Max RSSPL* measured has higher accuracy than location estimate in RSS case, as the result proved the distance between the estimated and true positions tags are decreased based on *Max RSSPL*, meaning that the estimated position quite close to the actual tag position, that leads to increase the accuracy of localization estimation and the localization result is reasonable. The simulation given in chapter five, this result proved that the accuracy of localization estimation based on *Max RSSPL* was improved.

In this dissertation, has also presented the localization estimation of RFID tags by comparing the propagation parameters for Multilatration, LANDMARC and MDS algorithms. In order to infer the tag-to-reader distances and estimate inter-tag distances from the RSS measurements, the log-normal path loss model and the triangular method are defined. MDS algorithm has been demonstrated through the simulation experiments. It achieves high estimation accuracy for the tags localization and tolerates error gracefully due to the overdetermined nature of the solution. It's very helpful for the localization, notably, the estimated distance can be very rough indeed. Classical metric MDS has an analytical solution, it can be performed efficiently on large matrices, whereas LANDMARC requires more reference tags around the tracking tag in order to provide better location information, i.e., it decreases greatly with a lower density of reference tags. Thus, there is a tradeoff between the accuracy and number of reference tags. Multilateration is the problem of estimating a node's position from ranges to three or more known nodes (sensors), If not all nodes have ranges to at least three sensors, their positions must be estimated through an iterative process. In addition, the refinement to the localization problem using *Max RSSPL* readings can significantly improve the localization estimation performance. Using MATLAB based simulations we have evaluated the performance of our algorithms.

6.2. Future Work

In terms of future work, there are a few extensions based on identification and localization algorithms can be considered in the future,

1. For RFID identification tags, includes applying RFID Identification /tracking for Bank customers. However, it should be taken into consideration, RF signals exhibit multipath propagation due to the environment effect from obstructing structures such as walls and corridors in the bank.
2. In this work, use the log-normal path loss model to infer distances from RSS measurements in order to construct the distance matrix as the input for MDS. LANDMARC is unlike Multilateration and uses a different approach that directly matches the RSS of the target tag with the RSS of the reference tags. LANDMARC has two phases: one with the RFID tags uniformly distributed in the reference tags' interior area, and the other with the RFID tags are not distributed in the readers' interior area. It is noteworthy that, if RFID tags are not carefully chosen to cover the whole deployment area and RFID tag is not in the interior area of the reference tags, the localization error of LANDMARC can be significantly worse and undesirable estimates when RFID tags satisfy this condition, i.e., the layout of reference tags may affect significantly on the location accuracy of this algorithm. In order to further improve the localization accuracy using maximum likelihood estimation at the expense of additional computation costs.

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ΒΙΟΓΡΑΦΙΚΑ ΣΤΟΙΧΕΙΑ ΤΟΥ ΥΠΟΨΗΦΙΟΥ

Ο υποψήφιος διδάκτορας κ. Rashid Ahmed γεννήθηκε στο Ιράκ στις 18 Σεπτεμβρίου του 1975. Ολοκλήρωσε τις σπουδές του (πτυχίο και μεταπτυχιακό) στο Πανεπιστήμιο Τεχνολογίας της Βαγδάτης. Από το Νοέμβριο του 2010 είναι υποψήφιος διδάκτορας στο Τμήμα Ηλεκτρολόγων Μηχανικών και Μηχανικών Υπολογιστών, του Εθνικού Μετσόβιου Πολυτεχνείου. Η συμβολή της διατριβής του αφορά τον τομέα Συστημάτων Ταυτοποίησης μέσω Ραδιοσυχνοτήτων (RFID).

Κατά τη διάρκεια του 2011, πέτυχε στα διάφορα μαθήματα της Σχολής Ηλεκτρολόγων Μηχανικών και Μηχανικών Υπολογιστών, με μέσο όρο βαθμολογίας (9).

Στα πλαίσια της μελέτης του και για να δοθεί έμφαση στην ανάπτυξη του κατάλληλου συστήματος RFID και για την ολοκλήρωση ιδεών από τον τομέα των πειραμάτων ταυτοποίησης στο Εθνικό Μετσόβιο Πολυτεχνείο, πραγματοποίησε μια σειρά ταυτοποιήσεων σε εργαζόμενους στο Εθνικό Μετσόβιο Πολυτεχνείο Αθηνών (ΕΜΠ). Κατά την πρόσβαση των εργαζομένων σε μια συγκεκριμένη περιοχή του κτιρίου, εφαρμόστηκε ένα Σύστημα Ταυτοποίησης μέσω Ραδιοσυχνοτήτων (RFID) για την αναγνώριση παρέχοντας ειδικά σήματα που περιέχουν ετικέτες RFID.

Παράλληλα με την ερευνητική του δραστηριότητα, ο κ. Rashid συνέβαλε στην εξεταστική δραστηριότητα της Σχολής Ηλεκτρολόγων Μηχανικών και Μηχανικών Υπολογιστών. Συγκεκριμένα, στα ακαδημαϊκά έτη 2011-2014 επέβλεψε τις εξετάσεις των προπτυχιακών φοιτητών.

Ο κ. Rashid κατά τη διάρκεια των μεταπτυχιακών του σπουδών, παρήγαγε σημαντικά ερευνητικά αποτελέσματα, τα οποία έχουν δημοσιευθεί διεθνή επιστημονικά περιοδικά.